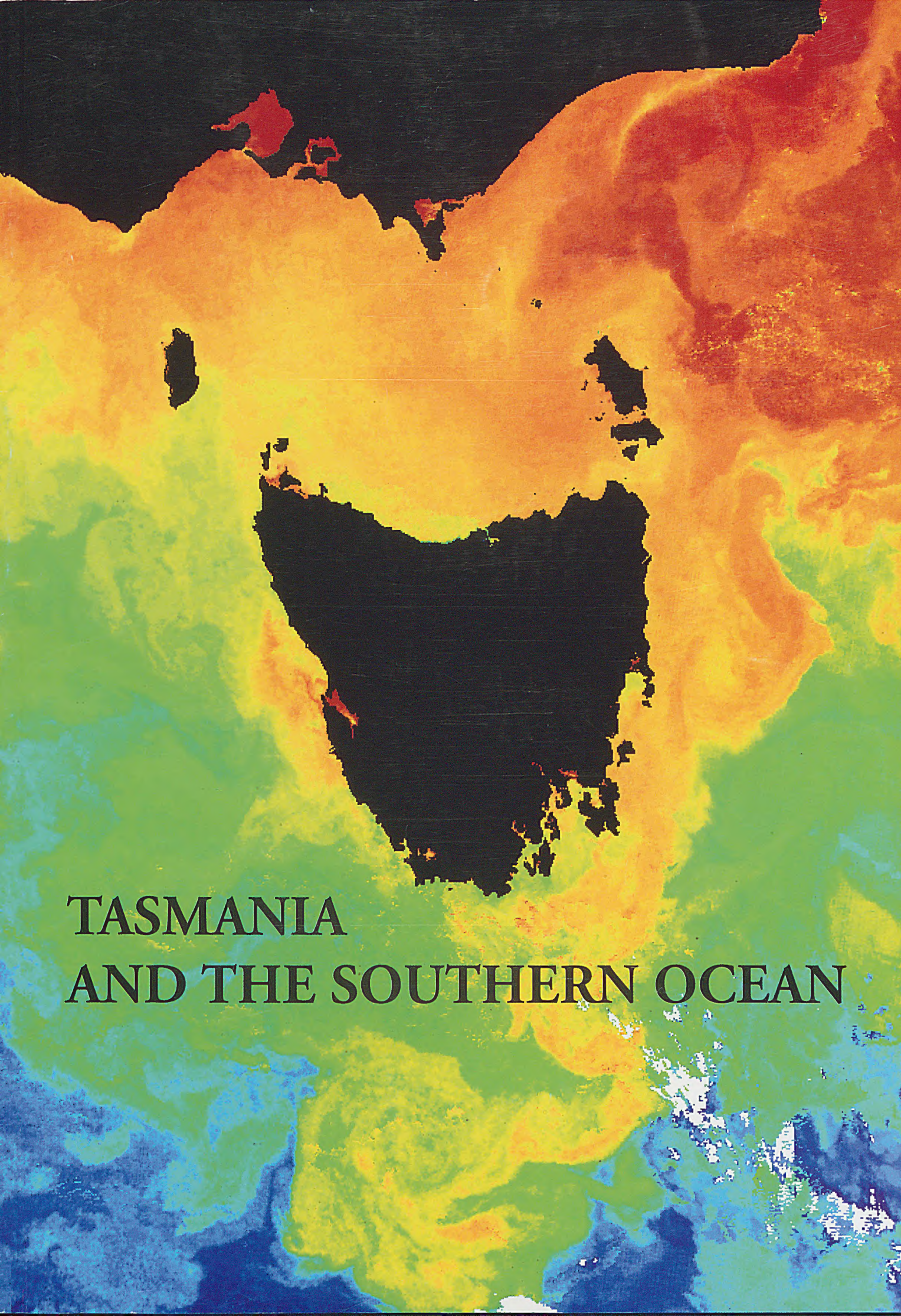

TASMANIA AND THE SOUTHERN OCEAN

Department of the Environment

Tasmania

DEPARTMENT *of*
PRIMARY INDUSTRIES,
WATER *and* ENVIRONMENT

MUSEUM VICTORIA
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PAPERS AND PROCEEDINGS OF THE ROYAL SOCIETY OF TASMANIA
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Dr G. Cresswell, CSIRO Division of Oceanography

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THE OCEAN PLANET
Plenary Address to the ANZAAS Conference, Hobart, 30 September 1998

by Dr Nan Bray
Chief of CSIRO Marine Research

BRAY, N., 2000 (31:v): The Ocean Planet: Plenary Address to the ANZAAS Science Conference, Hobart, 30 September 1998. *In* Banks, M.R. & Brown, M.J. (Eds): *TASMANIA AND THE SOUTHERN OCEAN. Pap. Proc. R. Soc. Tasm.* 133(3): 1–3. ISSN 0080–4703. CSIRO Marine Research, GPO Box 1538, Hobart, Tasmania, Australia 7001.

The economic importance for Australia of ocean-based activities is already large and the potential immense. Major discoveries arising from research in the last few years provide great promise and indicate the importance of adequately funded research. If past abuses are to be corrected and future abuse avoided, there is urgent need to develop a program of multiple use management. If the commercial, aesthetic, cultural and conservation values of our marine environment are to be realised, funding for the necessary research must be provided now. [Ed.]
Key Words: ocean, marine resources, marine research, tourism, sustainable development, oceans policy, Tasmania, Australia.

In the 15th century the nations of Europe discovered the deep sea. It was an alien and forbidding place that seemed to offer little but danger. The coastal waters were rich with fish and other marine life. Within sight of the European coastline there was an abundance of seafood. There was no need to fish unknown and inhospitable waters, and what else was out there except dragons, demons and angry gods?

Yet the nations of Europe prospered in direct proportion to their mastery of the open sea. Spain and Portugal amassed stunning wealth and virtually ruled the world, because they perfected the arts of navigation and seamanship.

Today the world is facing a similar situation. The ocean holds out a promise of wealth and prosperity to those nations that will learn how to work with her in harmony. That is why the Australian Marine Industries and Sciences Council, in its 1997 report, said :

> marine areas are seen by many as one of the last relatively unexplored resources and frontiers for industry development. Consequently, countries, which develop leading edge marine industries or technologies, have the potential to supply a very wide international demand.

What could be more natural than to see a great island nation like Australia, a nation that worships her oceans, develop this national attribute into a source of broad economic strength? It would seem to be the most natural thing in the world, but it may not happen unless we begin to get serious about understanding our oceans.

The oceans are virtually untapped resources. Today we stand before the oceans as our ancient ancestors once stood before the land, as mere hunter-gatherers, only beginning to understand the power to be released by the secrets of farming, husbandry, harvesting and mining within a vital new resource. How far back must we look to find the time when we knew as little about how to use the land, when we were only beginning to understand the rudiments of agriculture and husbandry?

There are two reasons why marine research is vital to our future. First, it is needed in order to make the most of our marine opportunities. Second, it is essential in order to understand and monitor environmental reactions and to ensure that marine resources are developed in a responsible and sustainable manner.

The marine operating environment is both hostile and sensitive. Marine industries develop through improved knowledge of the resource, through technical innovation and development, and through better knowledge of the operating environment. Research is vital to this process.

When we say that there are large rewards to be gained through understanding and accessing ocean resources — what do we mean? Are we talking really big sums? Are we talking about something that is worth more to us than wool, or wheat, or coal or oil and gas?

Yes! In fact, right now marine resources earn Australia more than all her agricultural production, both livestock and crop, and all the flow-on industries that support agriculture. Furthermore, marine resources are growing at a rate two to three times the annual growth rate of our economy. Marine resources are big and rapidly getting bigger.

In 1984 our marine resources were worth about $16 billion a year, today they are worth about $52 billion, by 2020 they will exceed $120 billion a year. Australia's marine resources are growing so rapidly they represent one of the most buoyant sectors of the economy and a major area for new industry and job creation.

It is always rather difficult to pin down earning from marine resources, since marine resource are not seen as a separate area when compiling Australia's economic statistics. Anyone questioning our estimates for current marine resource earnings will find the following research into marine tourism enlightening.

The Bureau of Tourism Research reported that marine tourism is a significant proportion of Tourism in Australia, comprising 50% of international visits and 42% of domestic visits.

The Department of Industry, Science and Tourism commissioned a report on the impact of coastal and marine tourism, based on information obtained from 44 geographical regions that comprise coastal areas around Australia. Only non-business visitors were included in the survey.

The survey found that, in 1995–96, expenditure on coastal and marine tourism was $23 billion. This represents 3% of Australia's total expenditure on goods and services. When the flow-on effects are added, the total expenditure attributable to marine tourism is $36 billion a year, or 5%

of the Australian total for goods and services. This also represents 5% of the Australian full-time equivalent workforce, 5% of total Australian wages and 5% of Australia's gross domestic product.

Marine tourism is a very large portion of Australia's economy and is directly interrelated with other industries within the marine resource area, such as commercial fishing, aquaculture, shipping, oil, gas and seabed mining. The continued success of our marine tourism is linked to the sustainable use of the total marine resource, and could be seriously damaged by abuse of our oceans.

Damage through unsustainable use of marine resources may threaten the earning power of the whole marine area, which currently represents 6.5% of the gross national product and is the most vigorously growing sector of the Australian economy.

The entire marine resource area breaks down in this manner:

• tourism	$36 billion
• oil and gas	$10 billion
• shipping	$2.2 billion
• fisheries & aquaculture	$1.8 billion
• ship and boat building	$1.5 billion
• other	$0.5 billion
• total	$52 billion

Everyone wants and needs the knowledge that marine research provides. Without such knowledge, governments cannot make environmentally sound decisions. Ocean industries, from tourism to oil and gas, need access to the commonly held marine resource before they can produce income. They know that without the knowledge provided by marine research, the environmental lobby must push for an extremely cautious approach. Adequate marine research is in everyone's best interest.

Environmentalists, marine industries, scientists and the general public are all solidly behind the sustainable development of our ocean resources. The only way this can be achieved is through scientific and technical information employed in a program of multiple-use management. In this manner, the great economic benefits that are flowing from our marine resources can be accessed in the best possible manner.

Australia, under the United Nations Law of the Sea, is responsible for the third largest marine territory in the world. This marine territory will be the source of great economic benefit to Australia, but we are committed to developing it in an environmentally sustainable manner. It is important that we meet that international commitment. It is important that we do not make the same mistakes with the oceans that we made in developing the land.

Despite the rapid growth potential of our ocean resources, we know very little about our marine territory. We do not know enough to manage its development in a responsible manner. Within our ocean territory Australia has access to resources that include food, pharmaceuticals, minerals, oil and gas, and the use of the oceans for tourism, transport and recreation. Less than 5% of this marine territory has been physically mapped. Less than 2% has been mapped in terms of its habitat. We cannot begin to manage a resource, when we do not even know what is there to be managed.

We have little time. Because the benefits offered by our marine resources are so rich, development will take place. Unless our marine research program is stepped up, that development will take place without the knowledge needed to builded this resource in a responsible, sustainable manner. We will misuse our oceans just as we did our land. This time we will not do so out of ignorance — because we do know better. We will repeat our mistake simply through lack of resolve.

How little time do we have? CSIRO Marine Research has developed an amazing ability to fast-track the mapping of ocean habitat. We have the techniques to map 10 000 km^2 of ocean in two weeks, but we don't have the ships to do this.

If we had a ship devoted full time to this task we would finish the job in about 110 years. By that time the environmental disasters will have already occurred. Our Oceancare program will be well established, spending billions of dollars a year to correct our blunders.

But CSIRO Marine Research doesn't have a ship that can be devoted, full time, to such mapping. So it is unlikely that we will ever have the information needed to develop our ocean resources in a sustainable manner. If more resources could be devoted to such projects, and if areas of development were mapped first, it might be possible to keep pace with the rate of development.

If nothing is done, we will not have sufficient knowledge to ensure the sustainable, multiple-use management of ocean resources. This will make development decision-making, without hard information, tortuous. It will throw developers into wasteful, drawn-out media and legal battles, adding to the cost of all development. It will place regulatory agencies in the unenviable position of being forced into decisions they cannot support with firm data. They will be vulnerable to criticism no matter what decision they make. Our policy will be decided in the media and in the courtroom, and marine development will be slow and needlessly expensive.

How much are we spending now, through agencies such as Landcare, to reverse the mistakes we have made in the management of the land? Despite all the expenditure, how many of those mistakes are actually reversible? How does this expenditure compare with the funding to understand and manage our marine resources?

The Commonwealth Government supports Landcare projects that contribute to the sustainable management of land, water, vegetation and biological diversity. Each year $280 million is committed from the Natural Heritage Trust to Landcare. An additional 50%, $1 for each $2 spent by the Government, is allocated by more than 4000 Landcare groups across Australia. Funding is also made available locally and through state agencies.

Funding is complemented by Commonwealth support for Landcare activities, provided through a range of related grants, programs and tax concessions. New tax rebate and credit arrangements are being made available to encourage further investment in on-farm Landcare works.

In total, something like half a billion dollars a year is spent in trying to redress the mistakes we have made in managing the land. If we include tax deduction for Landcare activities, this may come closer to a billion dollars a year. In comparison, very little is spent to avoid making the same mistakes on the oceans.

Failure to act may cost us dearly, in terms of economic opportunity and the eventual cost of correcting our mistakes, but it may also have dire consequences in terms of our quality of life on the planet Earth. The vast and deep expanse of ocean that covers 70% of our planet is massive,

and slower to change than the atmosphere. The ocean acts as a regulator to stabilise many aspects of conditions on the Earth, such as climate.

Many environmental abuses, to which we have subjected our planet, have been soaked up and tempered by our oceans. Their impact is reduced by the resistance of the oceans to rapid change.

Although the stability of the ocean gives us latitude, it will not be endlessly forgiving. When we begin to affect the nature of the great ocean cycles, retribution will be fast and dramatic, and the process will be equally slow and difficult to reverse. It is important that we know how profoundly the oceans have been affected by out neglect, and how they are likely to react to it.

With the promise of so much before us, with so much to learn, so much to do, what are we, as a nation, actually doing? How are we to come to know and understand this ocean world for which we are responsible, which we are committed to manage well, and which promises so handsome a return on our investment?

We certainly mean well. The International Year of the Ocean, in 1998, gave us *Australia's Oceans Policy*, one of the world's first attempts at providing the kind of guidance needed in order to ensure sustainable use of valuable ocean resources.

Now we must find the way to turn policy into useful action. The ocean policy must be backed by the funding to make it work. It must include the kind of research funding needed to allow us to use our ocean resources safely and well.

Implementation of the policy must recognise marine resources as a special economic sector with needs of its own. At the moment there are not even any economic statistics kept on ocean resources. Fishing and aquaculture are considered to be a part of agriculture. Offshore oil and gas, or offshore mining are just a part of the mining statistics. Shipping is part of transport, marine tourism part of tourism, and so forth.

This is not good enough. All these areas are dependent upon access to our oceans. They affect our oceans, they affect other marine industries, they are closely linked and interrelated. Sustainable development of our marine resources depends upon a carefully devised multiple-use management program, based on scientific monitoring and research.

The people of Australia are proud of her wonderful oceans, as they should be. Although threatened, Australia's coastal and continental shelf waters are far better preserved than those in most of the world. And they are unique, as are the marine creatures that live there. The waters of the Southern Hemisphere contain many surprises for us.

In just the past five or six years, a volcanic province the size of Iceland was discovered off the Western Australian coast, and a cluster of deep-sea volcanoes, rising higher off the seabed than any of Australia's mountains, was found off Tasmania. In the last year, during routine sea exploration, a gas hydrate field was discovered off Lord Howe Island that has more energy potential then the Northwest Shelf. Such discoveries highlight the frontier nature of marine science in Australian waters.

What of biodiversity? We have an estimated 11% of the world's marine species, many of which are unique to our water. In the past decade, over 800 new species of fish have been identified in our marine territory. In one CSIRO survey of the deep-ocean seamounts 80 km south of Tasmania, new species were found in virtually every animal group, from corals and hydroids to crabs and fish.

A study on the Great Barrier Reef, by the Queensland Museum, found more than 4000 new species of sponges. Surveys conducted on Australia's upper continental slope have already found more than twice the number of species found on similar slopes in the Atlantic, even after decades of extensive survey work by American and European scientists.

Full realisation of the commercial, aesthetic, cultural and conservation values of our marine environment can only be achieved with proper understanding of how the marine systems work. This requires a bold and determined focus on marine research delivered and sustained by an ocean policy of true power and vision. We must insist on no less.

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AUSTRALIA'S OCEANS POLICY: A ROLE FOR SCIENCE?

by Angus McEwan

(with one text-figure)

McEwan, A., 2000 (31:v): Australia's Oceans Policy: a role for science? *In* Banks, M.R. & Brown, M.J. (Eds): *TASMANIA AND THE SOUTHERN OCEAN. Pap. Proc. R. Soc. Tasm.* 133(3): 5–10. ISSN 0080–4703. Bureau of Meteorology, GPO Box 727G, Hobart, Tasmania, Australia 7001.

The Commonwealth government's announcement in December 1998 of "Australia's Oceans Policy" heralds a bid to use agreed environmental principles as a basis for better-integrated Commonwealth–State planning and management of our marine assets.

The Policy defines a comprehensive implementation structure which should ensure consultation at all levels and a better link to the ministries of the relevant Commonwealth portfolios.

A focus on "ecosystem-based planning and management" reduces emphasis on some areas which could benefit from a clearly stated national policy. Marine science and the systems for delivery of data and information are not accorded any particular importance in the implementation of the Policy.

Key Words: Australia, Commonwealth Government, ocean, marine assets, environment, management, oceans policy.

PREFACE

This paper originated in one presented at the ANZAAS Conference, Hobart, 30 September 1998, shortly before the release by the Australian (Commonwealth) Government of "Australia's Oceans Policy" (AOP) in the last days of 1998 (Commonwealth of Australia [CoA] 1998).

The ANZAAS paper was intended to arouse public interest in the formulation of a comprehensive marine policy and it foreshadowed some of the important features of the AOP as it subsequently appeared, in particular the statement of a set of "principles" that would provide a template for decision-making and the definition of an organisational structure that has the potential to interface at many levels with the diverse governmental and non-governmental bodies on which the execution of properly planned and coordinated actions would rely.

This present paper reviews the policy in the context of its utility and its implications for the marine science needed in its implementation.

WHY AUSTRALIA NEEDS AN OCEANS POLICY

Our national anthem reminds us that "our home is girt by sea". Nevertheless, it has taken Australia's adoption in 1994 of the UN Convention on the Law of the Sea (UNCLOS) to raise awareness of the fact that the share of the globe for which we have sovereign control has more than doubled and that, apart from the inestimable value of the assets contained within our 12 million km^2 of Exclusive Economic Zone, Australian marine-related activity is estimated in excess of $30 billion turnover per annum (CoA 1997a). These assets are subject to a variety of State and Commonwealth government jurisdictions. Industrial practices in their usage are mainly regulated on a sectoral basis through the relevant departments. Overlaps and occasional contradictions arise in these jurisdictions and regulations. Worse, there has been little by way of an overarching and mutually agreed vision for use and custodianship and for resolving the numerous conflicts of interest, most notably between conservation and protection in the public interest and commercial or industrial usage. Further, management by regulation rather than cooperative action does not enable us to optimise the collective public benefit of these vast assets, now or for the future.

One advantage of a comprehensive national policy is that it promises integrated planning and division of responsibility between the various national departments, research agencies and non-governmental organisations with marine interests. As matters have evolved, the main document outlining the tasks (of the Commonwealth agencies at least) to be given priority and the infrastructural needs is the Marine Science and Technology Plan (MSTP) (CoA 1999), developed in parallel but fairly independently of the AOP. The MSTP was announced in July 1999.

UNCLOS and over 50 other relevant international instruments and treaties concerning the marine environment (CoA 1997b) to which Australia is signatory, reflect concern shared by many countries about the deterioration of the seas, the limits to sustainability of their living resources and the imperative need for concerted international action. Added to this is the manifestation of global warming, which, whether human-made or not, will impose unprecedented stress on whole marine ecosystems (Hoegh-Gulberg 1999, IPCC 1999).

UNCLOS has provided a useful fulcrum for the formulation of the AOP but a major goal, reflected in the themes of the accompanying papers rather than the text of the document itself, is to secure a more integrated and cooperative marine planning and management process with the State governments. It remains to be seen whether this can be achieved, but one state (Western Australia) has already indicated its reluctance.

THE EVOLUTION OF NATIONAL COORDINATION OF OCEAN AFFAIRS – A SCIENTIFIC PERSPECTIVE

As an aid to later discussion of the AOP, it is helpful to review the development of marine science coordination within Australia.

For managers of marine science, a long-standing difficulty has been the absence of an effective coordinating structure linking with government at a level appropriate to the scale of the tasks in hand. In spite of its maritime dependency, government long turned its back on the sea. Until the 1960s there was only a handful of marine scientists (in CSIRO – Mawson *et al.* 1998) and a little uncoordinated activity within the universities, although at international level Australia had a high profile. In the 1970s there was incremental expansion, including the establishment of the Australian Institute of Marine Science (AIMS) in Townsville.

Following on reports initiated by the Australian Science and Technology Council (ASTEC) in 1979 (CoA 1979) marine science expanded rapidly in the 1980s, with major growth within AIMS and two Divisions of CSIRO, the building of a research vessel (RV *Franklin*) as a national facility and the creation of a dedicated marine research grants scheme. Inter-agency and non-governmental coordination was effected through an Australian Marine Science and Technology Council (AMSTEC) and administered through the (federal) Department of Science.

In 1988 however, that department was eliminated, and marine responsibilities were transferred to the Department of Industry, Science and Technology. Attempts at co-ordination by broadly based sectoral committees (Committee for Marine Industries, Science and Technology [C-MIST] and Australian Marine Industry and Science Council [AMISC]) were ultimately unsuccessful.

Nevertheless, liaison between the agencies continued through an informal organisation, the Heads of Marine Agencies (HOMA) group. Apart from liaison, this group assumed responsibility (through its members) for Australia's governmental representation at UNESCO's Inter-governmental Oceanographic Commission (IOC) (which it had taken part in creating in 1961 and had subsequently chaired). Among its successes, HOMA has been responsible for creating a consulting company (Australian Marine Science and Technology Company [AMSAT]) drawing upon marine expertise within the agencies and establishing the Marine Data Group (MDG) which has established frameworks for the design and implementation of systems for the archiving and management of the nation's marine data holdings. This has been facilitated by the creation of Technical Advisory Groups (TAGs) comprising practising experts in separate disciplinary areas.

In spite of its success, HOMA has had little governmental support and has no defined place within the AOP or the MSTP.

The 1990s brought a period of change, funding uncertainty and governmental pressure in marine science. Major reviews, including the "McKinnon" review in 1989 (McKinnon *et al.* 1989), reiterated the need for better policy guidance and (repeated in 1993 – McKinnon 1993) a high-level Marine Industries and Science Council supported by and answering to government.

Reflecting government policies, the agencies (especially CSIRO) and universities have been increasingly dependent on external grants and commissioned work. There has been a corresponding decline in the amount of discretionary marine research, especially at the basic end of the spectrum.

ELEMENTS OF THE POLICY

Here, the implications of the AOP will be considered. For details of the content of the Policy itself the reader is referred to the relevant documents (CoA 1998).

A Unifying Theme: Integrated and Ecosystem-based Planning and Management

Reflecting both the leading role of the Department of the Environment and the need for a form palatable to the States, the theme for the Policy, cutting across the disparate and diverse marine sectors and entrenched interests, is based on the preservation of ecosystems in a multiple-use environment. This theme also facilitates the invoking of existing treaties and commitments, for example the *Inter-governmental Agreement on the Environment* (CoA 1992) and the *Heads of Agreement on Roles and Responsibilities* 1998 (cited in CoA 1998). This theme is rendered workable by execution in the context of regional marine plans (see section on Regional Marine Plans), because the ecosystems requiring protection are generally regional in character and because the sectoral interests being accommodated are likewise regional.

As the basis of a national policy, the weakness of this theme is that it excludes all that which is *irrelevant* to some ecosystem or other. Whole industrial sectors, for example ship design, may thus be excluded from consideration. In many more cases a long bow has to be drawn to link a line of study or development to ecosystem impact. If the Policy is used to define funding priorities then some worthwhile and important studies such as climate dynamics may have to be proposed on false promises or doomed to failure!

It might be argued that such "ecologically irrelevant" activities do not need to be part of a marine policy. However, few areas of study or management are more dependent on a wide spectrum of technical knowledge than the marine applications. The "integrated" approach needs to extend beyond the parties expected to comply with the policy but should embrace, in some way, those who design its implementation.

Principles

A set of stated principles is very important to a policy, because it enables the user to derive the practices to be applied in each individual case. The principles adopted for the AOP have been founded on those contained in previously agreed documents and are well worded. They have undergone extended scrutiny and endorsement in relevant governmental and non-governmental fora and are hard to contradict, well beyond the sense of "motherhood".

As for the "themes", the only criticism is what the principles do not include.

Structural Arrangements

An essential element of a new policy of such compass is an organisational structure that will press forward with detailed planning, guide its implementation and establish processes of consultation and review. A large proportion of the

$50 million pledged when the Policy was foreshadowed will be devoted to a structure that incorporates most of the attributes defined in models previously considered. The elements are these.

- *A National Oceans Ministerial Board* (NOMB), chaired by the Commonwealth Minister for the Environment and comprised of other commonwealth ministers with marine responsibilities. This will oversee the implementation and development of Policy issues, especially Regional Marine Plans, consult on Commonwealth expenditure and marine research priorities and promote strategic cross-agency coordination in relation to international marine fora. It will be advised by
- *A National Oceans Advisory Group* (NOAG, already established), comprised of experts, predominantly with non-government interests. This will advise on cross-sectoral and cross-jurisdictional issues and be a forum for information exchange between the ocean sectors The secretariat for the Board and the Advisory Group will be provided by
- *A National Oceans Office* (NOO). This office will support the Board and Advisory group, will coordinate implementation of the Policy and will be the administrative interface with the States and Territories, in the development and implementation of Regional Marine Plans. These Plans will be overseen by
- *Regional Marine Plan Steering Committees* (RMPSCs), one for each nominated region), comprising regional stakeholders, both governmental and non-governmental.

It is hoped that the Australian and New Zealand Environment and Conservation Council (ANZECC) will provide a suitable forum for Commonwealth–State consultation and coordination and the address of cross-jurisdictional issues, supported by the NOO in the consideration of oceans policy.

It should be noted that existing sectoral management arrangements will not be superseded by these arrangements, and that the prime basis for jurisdictional management will continue to be the Offshore Constitutional Settlement.

The NOAG has already been convened, and the NOO is being established in Hobart. It is noted that one additional role of the office is to "provide advice to the (NOMB) on marine research priorities related to the development of the Oceans Policy".

It is necessary to examine how the above structure relates to those that already exist and how new arrangements might add value. Existing Commonwealth and State agencies and departments need to have ownership of the total system of which they are part. This question is so broad that it will be addressed here only by considering a small part of the matrix, an example with which this author has some familiarity, *viz.* coordination relating to marine observing systems and national data management, in the context of structures already described in the earlier section on Evolution. This example serves as a good case study of the kinds of scientific issue that should benefit from the Policy since it combines

- existing activity and statutory responsibilities of existing State and Commonwealth agencies;
- a fairly large level of overlapping responsibility;
- levels of national coordination and support that are presently inadequate;
- broad cross-cutting importance in strategic terms;
- a low level of current prominence in government priorities.

A test is whether the structure can work from top to bottom. In the case of marine data, at the higher levels there needs to be an agreed national strategy with regard to marine environmental data, involving negotiation that should presumably proceed through the NOAG, in consultation with the Commonwealth Spatial Data Committee (CSDC) of ANZECC. The detailed consideration of implementation of the strategy should pass to a National Marine Data Group (NMDG) representing the agencies and departments involved. This group already exists on an informal basis as a subgroup of HOMA, and its formalisation is foreshadowed in the MSTP. It is essential that this should be guided by the people at the bench in the various national, state and university organisations who know how the technical tasks should be undertaken. These we combine in TAGs. The TAGs provide their detailed technical advice to the implementational agencies and feed up the line the issues that require higher level policy attention.

The prototype structure is shown in figure 1. It can be seen that effective linkages can be made and, in particular, that well-defined vertical pathways could be easily established. There is some duplication of the inter-agency coordination function between HOMA and NOAG, but the scale of the consultation process implies little redundancy.

REGIONAL MARINE PLANS

The essence of the Policy is in regionalised planning, stated to focus on ensuring ecosystem health and protecting marine biological diversity, while promoting sustainable marine industry and certainty and security for all marine users. It will rely on the development of a National Representative System of Marine Protected Areas (NRSMPA) and will defined through Regional Marine Plans. These plans will be defined by objectives for regional use, zoning and allocation, sector-specific requirements, industrial or other outcomes, and the required sustainability indicators, monitoring, reporting and management control mechanisms. The Policy emphasises the need for participation and cooperation between the Commonwealth and State governments in the process.

It is clear that the development of plans with these complex requirements will rely heavily on scientific expertise, information and data in two areas:

(i) in acquiring a working knowledge of (a) the resources and ecosystems in consideration, (b) basic biological inventories, and (c) the physical and dynamical characteristics of the region;

(ii) as the basis for prediction, monitoring and explanation of changes in response to any implemented strategy.

THE ROLE OF MARINE SCIENCE IN THE IMPLEMENTATION OF THE POLICY

For a policy so comprehensively reliant at all levels on scientific knowledge and expertise, it is perhaps surprising and somewhat disappointing that the AOP contains little to

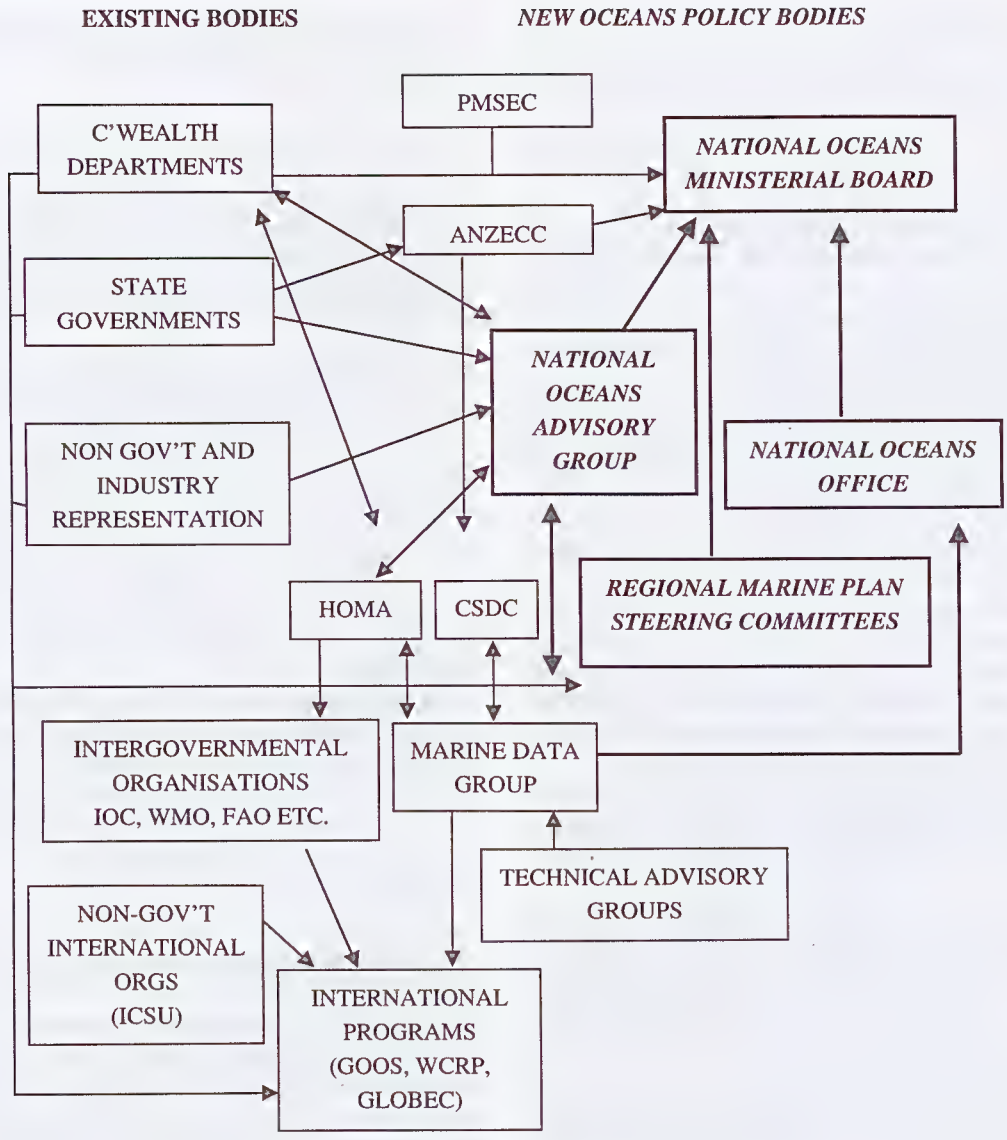

FIG. 1 — The new implementation arrangements for the AOP in relation to existing structures. For full list of acronyms, see Glossary, p.9.

reinforce the need for this scientific underpinning as an integral part of a national strategy. Indeed, it is implicit that the scientific community will answer the call as a service to the planners and implementers of the Policy, as the need arises.

The national scientific agencies will be represented in an advisory capacity in several of the groups and committees to be established. It is up to these representatives to ensure that the case for stability and continuity of support for the strategic development of marine science is put and carried to ministerial level.

The New Science Paradigm

In the above context, it is worth noting that technology, satellites, computers and the Internet are transforming the way environmental science is conducted worldwide, making it possible to combine the efforts of individual investigators in the concerted address of practical problems. Marine science, in particular, is developing this way, because the properties observed are spatially extensive and time-variable, and observations are, therefore, expensive and difficult. The exclusive "ownership" of data becomes an impediment, and there is a global trend to integrated observing systems and shared scientific and management tools. An Australian Ocean Observing system (AOOS) is in the early stages of implementation; this focusses on the integration and expansion of systems for monitoring the basic physical variables in order to incorporate them into near real-time computer models of the regional upper ocean on an "operational" basis. Such observations and models will provide the "boundary conditions" for finer-scale models of estuaries and coasts, which are powerful new tools for management and decision-making. It is hoped that the AOOS will in due course include non-physical variables and regional datasets. The coordination of this development will rely heavily on the NMDG and its TAGs, as mentioned in the section on Structural Arrangements above, which thus become an interdependent part of the structure illustrated in figure 1.

THE INTERNATIONAL DIMENSION

Better management of the marine environment is a pressing challenge for many nations, and a lack of expertise, resources or political will is an impediment to many of them. A solution is sought in international programs coordinated through UNESCO and its IOC, the World Meteorological Organisation (WMO) and UNEP, as well as a host of bilateral and multinational programs. The Global Ocean Observing System (GOOS), to which our AOOS will align to the appropriate degree, deserves particular mention, and there are components associated with GOOS, such as the Global Coral Reef Monitoring Network and the Global Data Assimilation Experiment, with which there is a special link. There are also a number of international scientific experiments coordinated non-governmentally through ICSU. Although our marine scientific development is on a par with the leading nations, our small size, short maritime history and the extent of our marine territory makes us very much a net beneficiary in the international exchange of knowledge and data. This is particularly so with regard to satellite-derived data, where we are totally reliant on cooperative partnerships, largely through the meteorological networks or the Committee on Earth Observing Satellites (CEOS), a non-governmental liaison of national space agencies. At an even larger scale, there are plans to link all global observations under a commonly-sponsored Integrated Global Observing Strategy (IGOS).

It is very important that these linkages are recognised, maintained and sponsored as an essential part of a national oceans policy. At present they are only alluded to in terms of the NOMB's responsibility to coordinate the participation of Australian agencies in international fora.

CONCLUSION

Australia has taken a timely and important step in creating Australia's Oceans Policy. An underlying intention is to provide a basis for better Commonwealth/State alignment in marine affairs, and the theme of "integrated and ecosystem-based oceans planning and management" provides a coherent and uncontroversial means to cut across the existing sectoral structures and jurisdictions.

The Policy incorporates a useful set of principles and defines an implementational structure that should link successfully on many levels with those already in place.

In focussing on an environmental theme, the Policy does not deal with related matters on which a national policy would be desirable. In particular, the role of science and technology on which its implementation will critically rely is treated as a service, covered under the supplementary Marine Science and Technology Plan, and there is a need for better recognition of the growing paradigm of integrated knowledge and data-sharing and of developments in marine environmental science at international level.

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GLOSSARY OF ACRONYMS

AIMS	Australian Institute of Marine Science
AMISC	Australian Marine Industries and Sciences Council
AMSAT	Australian Marine Science and Technology Company
AMSTEC	Australian Marine Science and Technology Council
ANZECC	Australian and New Zealand Environment and Conservation Council
AOOS	Australian Ocean Observing System
AOP	Australia's Oceans Policy
ASTEC	Australian Science and Technology Council
CEOS	Committee on Earth Observation Satellites (international)
C-MIST	Committee for Marine Industries, Science and Technology, convened by the Department of Industry, Science and Technology
CSDC	Commonwealth Spatial Data Committee of ANZECC
FAO	Food and Agriculture Organisation of UN
GOOS	Global Ocean Observing System, sponsored by UN
GLOBEC	Global Ocean Ecosystem Dynamics Experiment of IGBP
HOMA	Heads of (Australian Government) Marine Agencies Group
ICSU	International Council of Scientific Unions
IGBP	International Geosphere-Biosphere Program (of ICSU)
IGOS	Integrated Global Observing Strategy
IOC	Intergovernmental Oceanographic Commission of UNESCO
IPCC	Intergovernmental Panel on Climate Change
MDG	Marine Data Group, at present sponsored by HOMA
MSTP	Australia's Marine Science and Technology Plan
NMDG	National Marine Data Group
NOAG	National Oceans Advisory Group
NOMB	National Oceans Ministerial Board
NOO	National Oceans Office

NRSMPA	National Representative System of Marine Protected Areas
PMSEC	Prime Minister's Science and Engineering Council
RMPSCs	Regional Marine Plan Steering Committees
TAG	Technical Advisory Group
UNCLOS	United Nations Convention on the Law of the Sea
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific and Cultural Organisation
WCRP	World Climate Research Program, sponsored by UN
WMO	World Meteorological Organisation

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AUSTRALIAN OCEANS POLICY: IMPLICATIONS FOR MARINE ENVIRONMENTAL MANAGEMENT

by Bruce Davis

DAVIS, B., 2000 (31:v): Australian Oceans Policy: Implications for marine environmental management. *In* Banks, M.R. & Brown, M.J. (Eds): *TASMANIA AND THE SOUTHERN OCEAN. Pap. Proc. R. Soc. Tasm.* 133(3): 11–15. ISSN 0080–4703. Institute of Antarctic and Southern Ocean Studies, University of Tasmania, GPO Box 252-77, Hobart, Tasmania, Australia 7001.

Australia has one of the largest marine jurisdictions in the world. Attempts to develop an environmental management regime for this vast area were piecemeal until 1995, when it was announced an integrated oceans policy would be developed. Despite criticisms of process and content, the "Oceans Policy" released in December 1998 does provide a framework for resolving many maritime problems during the next decade.

Key Words: Australia, ocean, marine, environment, management, oceans policy.

INTRODUCTION

Australia has one of the largest and most diverse marine jurisdictions in the world, fronting three oceans and involving a number of offshore island dependencies, plus a significant proportion of coastal Antarctica. Managing such a substantial area poses particular problems for a middle-power federalist nation, more orientated towards terrestrial issues than maritime problems. Apart from the logistical difficulty of surveillance and enforcement, there are substantial constitutional legislative and administrative obstacles, highly diverse stakeholder perceptions and sectoral interests, some data deficiencies and limited research and development capability (Davis 1995).

These complexities have not inhibited the Australian Government from attempting to develop a national framework for handling marine environmental problems. While the Canadians have approached the issue via a single overarching statute, the Australian approach has been to develop a comprehensive policy framework in which various levels of government and major community interests all have an important role to play. The key question is whether effective collaboration and partnership can be achieved. It is too early to form an informed judgement about this; the most that can be claimed is that a variety of initiatives are being actively pursued, but the available budgetary resources are thin and widely spread.

In order to understand how the Australian Oceans Policy announced by the Prime Minister on 23 December 1998 came to fruition and what its implications are, we must first consider the national and international context, as well as earlier, somewhat more fragmentary approaches, and final coalescence to a coherent policy framework.

THE INTERNATIONAL CONTEXT

Australia's ratification, on 5 October 1994, of the United Nations Convention on Law of the Sea (UNCLOS) brought Australia into direct participation in a universal law-making instrument of enormous importance (Shearer 1994) and very considerable scope (320 articles and nine technical annexes). In effect, the area of national jurisdiction was doubled in terms of rights to natural resources and regulation of various activities, but Australia also entered into a series of international obligations then shared by more than 60 nations and with the longer-term prospect of many other countries becoming actively involved. Contrary to public perception, the rights assigned do not grant unfettered sovereignty; Australia is obliged to recognise a diversity of guiding principles and operational arrangements for various oceanic zones and sectoral fields (Rothwell 1996). One must also recognise that the UNCLOS was mainly drafted prior to 1982; thus, there are other environmental and fisheries issues which have required subsequent negotiation, and not all are finally resolved (Miles 1997, Johnson, 1996).

The UNCLOS does not exist in isolation; Australia is a party to at least 80 other international treaties, conventions and agreements, as well as a number of bilateral arrangements, such as the Timor Gap Treaty (Kaye 1995). While each regime may have been negotiated on the basis of individual need, ad hoc creation has led to numerous overlaps whose impacts, whether beneficial, benign or dysfunctional, are not yet fully tested (Herr & Chia 1995). There are few institutional instruments for harmonisation of these regimes, and the process of translating various international obligations into domestic practice (national statutes and policies) varies in speed and effectiveness from one country to the next (Kriwoken & Cote 1996). There is also the intriguing question of how to treat nations which are not yet party to such agreement or may act as renegades to particular initiatives within the international system.

The most that can be claimed is that multilateral cooperation on marine environmental issues is rapidly increasing, and that a body of formal and customary international law is steadily being developed and consolidated (Sands 1993).

THE AUSTRALIAN SITUATION PRE-1990

The Australian Constitution makes no mention of the term "environment", but this has not prevented both the States and Commonwealth from enacting various pieces of legislation aimed at perceived needs in nature conservation

and environmental management. In general, resource development, land-use planning, pollution prevention and protected areas management are the prerogative of the States and the Northern Territory, with the federal role limited to suasion towards common standards, research assistance and funding of diverse resource projects and programs (Davis 1991). Nonetheless, public opinion polls reveal a strong community expectation that the Commonwealth should take a leadership role and exercise reserve powers when circumstances dictate e.g. conservation of the Great Barrier Reef (Davis 1992). Moreover, international obligations place a responsibility on the Federal Government to ensure various international agreements are domestically implemented and provincial action meets specified criteria (Crommelin 1983, Zines 1985).

As the Oceans Policy Issues Paper (May 1998 – Commonwealth of Australia [CoA] 1998b) notes, in the early 1970s the States challenged the Commonwealth's assertion of maritime sovereignty under the *Seas and Submerged Lands Act* 1973. The High Court upheld federal jurisdiction to high-water mark, but in practical terms it was essential to grant the States some room for manoeuvre in respect of near-coastal waters (Haward 1989). A series of arrangements were entered into, giving the States and the Northern Territory title to three miles of territorial sea, subject to various conditions relating to security and other matters, the ensuing legislation entering into force in February 1982. Known as the Offshore Constitutional Settlement (OCS), the modus vivendii was not really off-shore, nor constitutional nor a settlement, there being several subsequent skirmishes between States and the States and the Commonwealth, especially with respect to offshore energy resources and fisheries problems (Haward 1992).

Federal action on marine environmental management had actually commenced in the 1960s, mainly with regard to limited and specific issues, such as marine pollution and the dumping of wastes. Australia became a party to a number of IMO (International Maritime Organisation) sponsored international agreements, such as the London Dumping Convention 1972 and MARPOL 73/78, the latter dealing with ship-sourced marine pollution. Other significant domestic initiatives included establishment of the Great Barrier Reef Marine Park 1975, the 1979 declaration of a 200 nautical mile Australian Fishing Zone (AFZ) and the Australian Government's key role in development of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), which entered into force in 1982. Inshore, all levels of government produced reports on fisheries problems and the need for improved coastal management, but these were rarely acted upon, given resistance from sectoral interests and lack of effective statutory authority or funding (Nguyen 1997). Numerous parliamentary reports noted such deficiencies, but were largely ignored, given the salience of other political issues (Haward 1996).

NEW DIRECTIONS, THE EARLY 1990S

During the early 1990s increased attention began to be given to marine environmental management. The catalyst, in part, was preparations for the 1992 United Nations Conference on Environment and Development (UNCED), but also criticism from a wide range of commentators about the fragmented character of Australian maritime activity and research (Bergin 1986, AIMS 1988, HOMA 1993, McKinnon 1993). The initial response was a statement by the then Prime Minister (the Hon. R.J. Hawke MP) in July 1989, referring a coastal zone inquiry to the Resource Assessment Commission (RAC), notwithstanding the fact that more than 60 coastal reports had been compiled from the 1960s onwards. Still, there were other initiatives, some of which are briefly summarised below.

- May 1992: An Intergovernmental Agreement on Environment was announced, aimed at improved collaboration between the States and the Commonwealth on environmental issues.

- December 1992: Release of a national policy on Ecology Sustainable Development (ESD).

- August 1993: Announcement of an Ocean Rescue 2000 package, subsequently expanded to include the following elements:
  – an Australian marine conservation plan;
  – a national representative system of marine protected areas;
  – preparation of a "state of the marine environment" report;
  – a national marine information system;
  – a national marine education program; and
  – the establishment of a Marine and Coastal Community network.

Impressive as this may appear, funding was thin and some elements are still being developed today.

- November 1993: Release of the Resource Assessment Commission's *Coastal Zone Inquiry: Final Report* (Resource Assessment Commission 1993). This recommended establishment of a national coastal action program, a coastal resources management Act and a national coastal management agency, the latter two proposals being ignored.

The Commonwealth did subsequently announce funding of a Coastcare Program, but took considerable time to develop the institutional arrangements essential to provide holistic and integrated action.

- 1993: The McKinnon report *Review of Marine Research Organisation* (McKinnon 1993) subsequently led to establishment of a Marine Industries and Science Council, but a development strategy did not appear until April 1996.

- 1994: The Australian Committee for IUCN (the World Conservation Union) produced a *Strategy for Conservation of Australia's Marine Environment* (Aust. Comm. IUCN 1994) and followed this up in March 1998 with a discussion paper on *Conserving Australia's Oceans* (Aust. Comm. IUCN 1998).

- 1995: Release of the first *State of Marine Environment Report* (SOMER) (CoA 1995), which provided an initial baseline, but highlighted five major concerns about the Australian marine environment, namely:

– declining marine and coastal water quality, particularly an outcome of inappropriate catchment land-use practices;
– loss of marine and coastal habitat;
– unsustainable exploitation of some marine and coastal resources;
– lack of integrated marine science policy; and
– neglect of long-term monitoring of the marine environment.

- 1995: Release of the joint CSIRO/AGSO/AIMS report *Ocean Outlook: A Blueprint for the Future* (Sci. Program Steering Comm. 1995). This document attempted to bridge the gap between scientists and managers, by identifying needs and opportunities for collaborative action, as well as outlining a research strategy for the future.

There are two observations one can make about these diverse initiatives: first, welcome as they were, most were ad hoc in character and neglected essential institutional needs in a field where vested interests and sectoral administration prevailed; second, a major opportunity was lost when Australia announced it would become a signatory to the UNCLOS in August 1994, the Convention entering into force in November that year. This was a time when community and political attention could have been captured about oceanic issues, but the Commonwealth announcement was little more than a normal press release.

Critics were quick to point out the need for more positive federal leadership, but the reluctant response from Prime Minister Paul Keating, in December 1995, was that an Australian Oceans Policy would eventually be developed, with no timeline or details specified. The only clue provided was a claim the policy would be based on sustainable use of resources, while conserving their biological viability. This rather tentative approach to oceanic issues may be attributable to preoccupation with terrestrial problems such as dryland salinity and water quality; Australian politicians were not yet attuned to a marine agenda.

THE OCEANS POLICY INITIATIVE 1995–98

This is not the place to detail the process by which a number of issue papers and consultancy reports were commissioned by Environment Australia and published in late 1997, apart from noting that a somewhat selective consultation process was involved and excessive reliance continued to be placed on assumed Commonwealth–State cooperation, which had not proven markedly effective in the past (Davis 1995). One positive achievement was that a wide range of marine environmental problems were addressed, the international context was noted and a number of marine planning models were analysed, as well as some management options. These documents provided a reasonably sound basis for national policy development, as long as some procedural and institutional difficulties could be overcome.

When the final overview Issues Paper (CoA 1998b) was released for public comment in May 1998, it effectively explained the need and aims of national oceans policy, stressing the need for a form of management which was ecosystem based, with sound scientific information, but it gave no details of intended priorities, anticipated outcomes or resourcing implications. While there was an environmental flavour to the report, many strategic, diplomatic, intergovernmental and conflict mediation aspects were entirely overlooked (Bateman 1997). In brief, this was somewhat thin treatment of rather complex and contentious matters, lacking vision or a clear plan of action. A starting point, but once again a great opportunity missed to move from piecemeal approaches towards more integrated strategy.

The term "marine environmental management" was not clearly defined in any of the discussion documents, although it was feasible to construe some perceived needs and guiding principles in individual issue papers. Section 2 of the Issues Paper (CoA 1998b) for example does identify elements of ecologically sustainable oceans management in terms of some planning provisions:

- planning for ecosystem health, but recognising the need for multiple use of resources;
- adopting a precautionary approach by recognising risk and uncertainty;
- noting the value of user-pays and other forms of economic instruments;
- the need to build collective community stewardship and provide transparency of decision-making;
- fostering ecologically sustainable resource use in all marine industries.

Underpinning all of this was recognition of the need to strengthen some sectoral capacities while pursuing more coordinated administrative action.

A valuable contribution to this debate was provided by the *Report of the Ministerial Advisory Group* on oceans policy, published in March 1998 (CoA 1998a). The collective opinions exposed, whether in agreement or disagreement, highlighted some of the problems to be encountered and overcome if an effective oceans policy was to be formulated and implemented. While recognising the need for sound scientific information, the Advisory Group was emphatic that strong Commonwealth leadership was required and that a variety of organisational difficulties needed to be overcome, including some jurisdictional questions and improved sectoral cooperation.

Without canvassing the nearly 100 recommendations made by the Advisory Group, some key concerns and proposals can be highlighted:

- understanding of marine ecosystems should be further developed;
- implementation of a National Representative System of Marine Protected Areas should be accelerated;
- State and Commonwealth legislative frameworks should be reviewed to ensure habitat protection and conservation of endangered marine species;
- the Commonwealth should adopt a leadership role in addressing land-sourced marine pollution;
- consideration should be given to tradeable rights in marine fisheries, but fisheries should be managed on an ecosystem and ESD basis;
- further research is required into aquaculture related issues;
- suggestions for improving the National Plans to combat oil pollution, deal with ballast water and combat introduced species should be considered;
- government–industry collaboration should be improved in research and management of offshore energy resources;

- urgent priority should be given to analysis and strategic planning of the marine tourism industry, since knowledge of its environmental impacts is poorly charted;
- indigenous communities should be widely consulted and actively involved in marine management;
- there should be increased integration of efforts in marine surveillance and enforcement; and
- the numbers, skills mix and training of individuals involved in oceans management and governance should be improved.

Some of these propositions were paralleled in a discussion paper prepared by the Australian Committee of IUCN (the World Conservation Union) released in March 1998, entitled *Conserving Australia's Oceans* (Australian Committee of IUCN 1998).

THE AUSTRALIAN OCEANS POLICY, DECEMBER 1998

When the final version of the Oceans Policy was announced by Prime Minister John Howard on 23 December 1998, it largely mirrored the content of the earlier Issues Paper, but had been fine-tuned to provide a little more detail. Two documents were released (CoA 1998c), the first dealing with contextual matters, the integrated and ecosystem-based approach, guiding principles, but also some key initial actions. The second document details specific sectoral measures, the need for public participation and performance evaluation. Overall these proposals were more positive and comprehensive than some critics had expected, particularly as they were sweetened by announcement of a $50 million allocation over three years for a range of actions associated with its implementation.

The Oceans Policy statement drew attention to the immense scale of Australia's Exclusive Economic Zone (EEZ) and the reality that Australia was the first nation to develop such a comprehensive framework for oceanic environmental management. Among the initial key actions to be undertaken were the following:

- development of marine regional plans, beginning with the southeastern region of the EEZ;
- strengthening baseline environmental surveys, sustainability indicators and monitoring programs;
- support for the development of a single national ballast water management system;
- creation of a nationally representative system of marine protected areas;
- measures to improve the sustainability of Australian fisheries, including improved effectiveness in preventing illegal fishing; and
- trials to treat some problems of land-sourced marine pollution.

In general these measures were well received and some are already being acted upon; nonetheless the overall picture remains one of a series of individually tailored programs rather than a cohesive whole. Perhaps this is inherent, given the diversity of interests and institutions involved and the necessity to negotiate a variety of agreements between the States, Territories and Commonwealth. Facilitation and cooperation may be engendered by a new federal agency, the National Oceans Office, which was announced in August 1999. A National Oceans Advisory Group has also been established, but its influence is largely dependent upon whether the Federal Minister for Environment is prepared to take its advice. Commonwealth–State cooperation may be engendered through bodies such as ANZECC (the ministerial Australian and New Zealand Environment and Conservation Council), but its role in the past has largely been to set common standards rather than strategic direction. Whether the latter will be achieved in the oceans policy area remains to be seen.

IMPLICATIONS AND FORWARD AGENDA

Commentators on the maritime agenda are pleased that release of the Oceans Policy statement has initiated a new regime, but critics are mindful of the reality that in the past competition between the Australian States for economic development has led to attrition of natural resources (Toyne 1994). The forward agenda does contain a number of interesting challenges:

- the current policy says little about Australia's role in international marine environmental management;
- there is a significant loss of coastal and marine habitat and many Australian fisheries are under sustainability threat;
- almost 70% of marine pollution arises from land-sourced origins and no government has yet seriously contemplated how this terrestrial–marine dilemma should be administratively handled;
- there is a serious threat from introduced marine species which are proving costly and difficult to eradicate; and
- given Australia's immense coastline, it is difficult to devise remedial plans to deal with critical incidents, such as oilspills or illegal incursions by foreign fishermen or clandestine immigrants.

In addition to the above there is a new and indeterminate factor, namely advent of the *Environment Protection and Biodiversity Conservation Act* (Cth) 1999, which was passed with remarkably little parliamentary debate, despite its complexity and powerful implications. In theory, the new statute limits Commonwealth environmental action to six fields of "national significance", including Federal offshore areas, but leaves many matters to the discretion of the Minister and involves negotiated agreements with the States and Territories. Many aspects of implementation remain to be specified and tested.

If one considers the Oceans Policy statement in isolation, it correctly adopts a proactive rather than reactive approach. The agenda is immense, the resources are limited; thus collective ownership must be fostered. This is the central challenge in rendering the Oceans Policy operational, during the first decade of the third millennium.

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(accepted 16 November 1999)

A PROBLEM WITH ECOLOGICALLY SUSTAINABLE DEVELOPMENT IN AUSTRALIAN WATERS

by F. R. Harden Jones

(with one table)

HARDEN JONES, F.R., 2000 (31:v): A problem with ecologically sustainable development in Australian waters. *In* Banks, M.R. & Brown, M.J. (Eds): *TASMANIA AND THE SOUTHERN OCEAN. Pap. Proc. R. Soc. Tasm.* 133(3): 17–19. ISSN 0080–4703. Institute of Antarctic and Southern Ocean Studies, GPO Box 252-77, Hobart, Tasmania, Australia 7001.

A federal court decision has ruled that social and community issues are irrelevant to the Australian Fisheries Management Authority in pursuing its statutory objectives laid down in the *Fisheries Management Act* 1991. The matter is discussed in relation to recent policy statements put forward by Australian Governments.

Key Words: fisheries management, AFMA, Bannister Quest, ecologically sustainable development, national strategy, Australia's Oceans Policy.

INTRODUCTION

The Australian Fisheries Management Authority (AFMA) undertakes the Commonwealth's fishery responsibilities in Australia's Exclusive Economic Zone which includes the sea areas around Australia's Subantarctic islands.

AFMA has been receiving a lot of flak recently, both in and out of the courts. Tasmanian fishers have problems with AFMA over the allocation of trevalla or blue eye *(Hyperoglyphe antarctica* Carmichael) quotas. In Hobart, George Mure has been vociferous on this matter — and on the Mure-path — for several months.

Richard Stevens was until recently the Managing Director of AFMA. He was reported in the newspapers as saying that social and community matters were of no concern to AFMA, or words to that effect. I was surprised. But Mr Stevens is correct, and he was correctly reported in the press.

AFMA's position follows from *Bannister Quest Pty Ltd* v. *Australian Fisheries Management Authority* (1997) 77 FCR 503-551 before Drummond J on 14 August 1997 at Brisbane (hereafter Bannister Quest). In this case Mr Will Nichols (a Melbourne fisher) appealed against an AFMA decision that he could not use a vessel over 32 m in length in the South East Fishery. AFMA appeared to have refused entry because operators with smaller vessels might be disadvantaged.

AFMA'S OBJECTIVES

AFMA was set up under the *Fisheries Administration Act* 1991 and AFMA's objectives are set out in the *Fisheries Management Act* 1991 (hereafter FM Act) Section 3. This section, dealing with objectives, reads as follows:

> 3. (1) The following objectives must be pursued by the Minister in the administration of this Act and by AFMA in the performance of its functions:
>
> (a) implementing efficient and cost-effective fisheries management on behalf of the Commonwealth; and
>
> (b) ensuring that the exploitation of fisheries resources and the carrying on of any related activities are conducted in a manner consistent with the principles of ecologically sustainable development, in particular the need to have regard to the impact of fishing activities on non-target species and the marine environment; and
>
> (c) maximising economic efficiency in the exploitation of fisheries resources; and
>
> (d) ensuring accountability to the fishing industry and to the Australian community in AFMA's management of fisheries resources; and
>
> (e) achieving government targets in relation to the recovery of the costs of AFMA.
>
> (2) In addition to the objectives mentioned in subsection (1), or in section 78 of this Act, the Minister, AFMA and Joint Authorities are to have regard to the objectives of:
>
> (a) ensuring, through proper conservation and management measures, that the living resources of the AFZ are not endangered by overexploitation; and
>
> (b) achieving the optimum utilisation of the living resources of the AFZ;
>
> but must ensure, as far as practicable, that measures adopted in pursuit of those objectives must not be inconsistent with the preservation, conservation and protection of all species of whales.

TRUE CONSTRUCTION OF AFMA'S OBJECTIVES

Here I will follow the text of Mr Justice Drummond in Bannister Quest without reference to other legal authorities.

There is a difference in the wording of Section 3 (1) and Section 3 (2). Section 3 (1) reads "...must be pursued..." This is a statutory imperative and AFMA would be in breach of its duty if the five objectives (a to e) were not pursued. While all the objectives in Section 3 (1) are of equal importance

> there will be cases in which the Minister may give varying degrees of weight and emphasis to this or that objective. So long as each objective is pursued, there will be no breach of duty. But if one of the objectives is not pursued at all, then that will not be the case. [Bannister Quest, 513 E, F, G; 514 A.]

In contrast Section 3 (2) of the FM Act reads "... are to have regard to ..." and is less demanding. The objectives in Section 3 (2) of the FM Act are the same as those in Section 5 B of the *Fisheries Act* 1952. And in the FM Act the phrase "optimum utilisation" in Section 3 (2) contrasts with "maximise economic efficiency" in Section 3 (1).

MR JUSTICE DRUMMOND'S DECISION

In making a decision in Bannister Quest, Mr Justice Drummond had to decide the true meaning of the objectives in Section 3 (1) of the FM Act and his interpretations of Section 3 (1) (b) and (c) are relevant to the theme of this paper.

I will take Section 3 (1) (c) first. What does "maximising economic efficiency in the exploitation of fisheries resources" mean in the context of the FM Act? As Section (1) (c) is a statutory obligation which AFMA has to pursue, the meaning of the phrase should be determined by statutory construction and not by reference to textbook economics (Bannister Quest, 514 B, C).

Mr Justice Drummond considered much of the language in Section 3 (1) of the FM Act to be "obscure and ambiguous" (Bannister Quest, 514 E, F). Curiously, neither "economic efficiency" nor "ecologically sustainable development" is defined in the FM Act. Under these circumstances the *Acts Interpretation Act* 1901 Section 15 AB indicates the extrinsic material that may be used in the interpretation of obscure and ambiguous Acts.

Briefly, the material must have been before Parliament, or its members, before the Bill was enacted. Government policy statements and the Minister's speech at the second reading are among the material that may be relied on.

From the Minister's (then Mr John Kerin) speech and the Government Policy Statement *"New Directions"*, Mr Justice Drummond concluded that the concept of "economic efficiency" referred to in Section 3 (1) (c) of the FM Act was

> productive efficiency in the sense of maximising output at least cost to the operators of the vessels comprising the fishing industry ... [Bannister Quest, 515 E, F, G.]

Furthermore, he concluded that, in pursuing the objective in Section 3 (1) (c), AFMA is to be concerned with profits at the industry level and not with the situations of individual fishers; and that

> there is no room for AFMA, in seeking to maximise economic efficiency in the exploitation of fishery resources, to take into account social and equity considerations ... [Bannister Quest, 519 E, F, G.]

I now come to Section 3 (1) (b) of the FM Act, which refers to the principles of ecologically sustainable development. The dates of some events and publications are summarised in table 1. Only *New Directions*, the Government policy statement, satisfies the conditions of the Acts Interpretation Act relating to the use of intrinsic material. But "ecologically sustainable development" (ESD) appears to be mentioned only once in *New Directions*, on p. 1, para. 2, lines 3–4. "Ecologically Sustainable Development" does not even appear in the Glossary.

Following *New Directions* and the Minister's second reading speech to Parliament, Mr Justice Drummond decided that

> Section 3 (1) (b), on its true construction, requires AFMA, in pursuing this objective in the performance of its functions, to limit its consideration to matters that relate to two things, ensuring the biological sustainability of fish stocks and ensuring the protection of the marine environment upon which those fish resources depend. [Bannister Quest, 526 E.]

So social, community and equity consideration and the like are irrelevant to AFMA in the pursuit of its statutory objectives. Mr Will Nichols won his appeal and his costs.

TABLE 1
Dates of events or publication of documents relevant to Ecologically Sustainable Development

Year	Month	Event
1983		*Fisheries Act* 1952 reprinted
1987		WCED, Our Common Future (Brundtland Report) published
1989	Dec	*New Directions* published
1990	Nov	ESD WG Fisheries first meeting
1991	Oct	ESD WG Fisheries last meeting
1991	Oct	ESD WG Fisheries report published
1991	Nov	FA Act and FM Act assented,
1992		*National Strategy for ESD* published
1998	Mar	Oceans Policy (Report) published
1998	Dec	Oceans Policy 1 published
1998	Dec	Oceans Policy 2 Specific Sectoral Measures published

FISHERIES MANAGEMENT, ESD AND THE FUTURE

But the Judge's interpretation of the true meaning of Section 3 (1) (b) of the FM Act may not be what governments had in mind. Thus the *National Strategy for ESD*, referring to the guiding principles of ESD, indicates (Anon. 1992: 8–9) that the

> decision making processes should effectively integrate both long and short term economic, environmental, and social and equity considerations ...

and (Anon. 1992: 8–9) that the

> ... guiding principles and core objectives need to be considered as a package. No objective or principle should predominate over the others. A balanced approach is required that takes into account all the objectives and principles to pursue the goal of ESD.

The report of the Ministerial Advisory Group on Australia's Oceans Policy notes (Anon. 1998a: 21, para. 6) that

> management for ecological sustainable development of the fisheries industry requires consideration of the economic, social and environmental aspects of all fishery sectors.

And the *National Strategy for ESD* includes a very clear statement of intent (Anon. 1992: 27) that governments will

> review, and where necessary amend, fisheries legislation to ensure it provides the basis for managing the fishery resource in ways which are consistent with the principles of ESD.

On p.27 (at dot point 3) in the National Strategy, a distinction is implied between "an ecosystem approach" and "the principles of ESD". There is indeed a difference between them. An ecosystem approach to management is concerned with the resource (and its environment) that fishers pursue. But ESD must also include the resources that industry uses at the catching, processing, marketing and consumer levels. And all these levels, or sectors, involve social, community and equity concerns.

However, it now seems likely that the Government will limit its review of fisheries laws and regulations to streamlining and minimising compliance costs for small businesses (Anon 1998c: 10, col. 1, dot point 7*)*.

As the CSIRO member on the Fisheries ESD Working Group (WG F ESD 1991), I attended 14 of the 16 meetings and kept detailed notes of the discussions: some were explosive.

At the second meeting, Dr Andrew Constable gently drew our attention to the need to develop alternative management strategies in the absence of data whose cost of collection could exceed the value of the fishery.

At the third meeting, there were many objectors, led by Dr Bob Kearney (then Director of the NSW Fisheries Research Institute at Cronulla), to the concept of "maximising" economic efficiency when "optimising" seemed more appropriate. Later Mr Geoff Gorrie, Director of the Australian Fisheries Service, carried out "damage control" in respect of the use of "maximisation" in *New Directions* and finally conceded that this was really a "constrained maximisation".

At the fourth meeting, Dr Bruce Davis gave as his view that the economic and social factors associated with ESD might prove to be more difficult than the "fishery" problems. Subsequent events bear out his concerns.

Finally, my notes of the fifth meeting record that there was a very loud and prolonged argument over definitions. I kept quiet: when the lions roar, it behoves the lesser animals to remain silent. But the experience stimulated me to start work on the glossary and anthology that was later published (Harden Jones 1994) with assistance from IASOS and the Fisheries Research and Development Corporation.

I think, indeed I rather hope, that there will be more arguments in the future.

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CURRENTS OF THE CONTINENTAL SHELF AND UPPER SLOPE OF TASMANIA

by George Cresswell

(with seven text-figures; figure 4 in colour)

CRESSWELL, G., 2000 (31:v): Currents of the continental shelf and upper slope of Tasmania. *In* Banks, M.R. & Brown, M.J. (Eds): *TASMANIA AND THE SOUTHERN OCEAN. Pap. Proc. R. Soc. Tasm.* 133(3): 21–30. ISSN 0080–4703. CSIRO Division of Oceanography, GPO Box 1538, Hobart, Tasmania, Australia 7001.

Satellite-tracked drifters, satellite imagery, a research vessel and moorings in the waters of Tasmania, excluding Bass Strait, revealed a southward current, sometimes called the Zeehan Current, on the outer continental shelf of western Tasmania. The current has a peak speed in winter, when it reaches around southern Tasmania as far north as Schouten Island before veering southeastward under the influence of the East Australian Current. In summer, the Zeehan Current is weaker, while the East Australian Current is stronger and overshoots southward past Tasmania by about 200 km, entraining the Zeehan Current in the process. Off western Tasmania, well seaward of the Zeehan Current, the residence time for satellite-tracked drifters was as much as one year. More than 200 km south of Tasmania in summer there was weak flow to the west. Eleven of 13 satellite drifters released in Tasmanian waters eventually meandered eastward towards New Zealand, with a travel time of over 18 months from the time of release.

Key Words: sea-surface temperatures, Zeehan Current, East Australian Current, long-term drift, Tasmania.

INTRODUCTION

In some ways Tasmania can be thought of as set in or influenced by three oceans: the Pacific on the east, the Indian on the west and the Southern on the south. Of course, this is oversimplified, but it does give some clues as to the potential complexity of the currents and water properties in the region. As compared to other Australian waters, those of Tasmania have been subject to very little study. Even the maritime approach of assembling ship drifts to produce monthly current charts was thwarted by lack of data over extensive areas west of Tasmania (Koninklijk Nederlands Meteorologisch Institut 1949).

Wood (1954) interpreted distributions of dinoflagellates to postulate that a current flowed eastward from Cape Leeuwin to King Island and suggested that confirmation came from the finding of warm-water turtles on the west coast of Tasmania. He pointed out that such a current was in keeping with the current atlases presented by Schott (1935). Drift bottle studies off western Tasmania (Vaux & Olsen 1961) suggested that in winter an eastward current from South Australia split offshore from western Victoria, with part entering Bass Strait and part running southward along western Tasmania. This branch then turned and ran northward off eastern Tasmania. In summer, drift bottle releases/recoveries suggested a northward current off western Tasmania that was joined by water from Bass Strait to flow to the Great Australian Bight. Newell (1961) felt that the seasonal alternation of the circulation was due to the north–south migration of the Australian atmospheric high pressure zone. The southerly winds in summer, he suggested, probably drove Subantarctic water (14°C, 35.0 psu) northward off western Tasmania. However, at the same time, he felt that subtropical water (>35.5 psu) from the southern Indian Ocean reached western Tasmania in the westwind drift, causing summer strandings of subtropical and tropical fauna, such as *Physalia*. In a later paper, Newell (1974) found that the upper waters encountered off southeastern Tasmania in winter were derived from the region to the west and northwest of Tasmania, once again pointing to southward flow off western Tasmania in winter.

Temperature sections between Melbourne and Antarctica in summer showed warm southward flow above the continental slope at the western entrance to Bass Strait (Edwards & Emery 1982), and this was named the Zeehan Current by Baines *et al.* (1983). It was thought to be about 40 km wide and permanently southward, rather than seasonally reversing as claimed by Newell (1961) and Vaux & Olsen (1961). Baines *et al.* (1983) had no information on the currents of the continental shelf. The first long-term moored current meter data were obtained by Lyne & Thresher (1994) at four sites across the western Tasmanian shelf and slope between June and November 1988. The currents were consistently southward and strong at the shelf edge, averaging 0.3 ms^{-1}. Off eastern Tasmania, Harris *et al.* (1987) concluded that the seasonal and interannual variability could be explained by the varying location of the subtropical convergence off the central eastern Tasmanian coast.

With a view to better understanding the relationship between coastal, shelf and open ocean currents, we released 13 satellite-tracked drifters with drogues at 15 m depth on the continental shelf around Tasmania from 1991–94 and we examined satellite sea-surface temperature images of the region. In March and December 1997, we carried out two ship surveys with the RV *Franklin* along a number of transects from nearshore to the 2000 m isobath to the west, south and east of Tasmania. Two acoustic Doppler current profilers (ADCPs) were moored at the 100 and 200 m isobaths off western Tasmania for 11 months from March 1997. The initial results of this work are discussed in this paper.

INSTRUMENTATION

East Australian Current satellite-tracked drifters have a cylindrical surface unit (0.6 m long by 0.2 m diam.) with a 0.5 m whip antenna. The unit floats 70% submerged and is attached by a 4 mm diameter cable to a small subsurface float and thence to a "holey sock" drogue that is 5 m long and 1 m diam. The centre of the drogue is at a depth of 15 m.

The surface unit measures sea temperature, battery condition and tilt. It transmits this information and an identification code at 410 MHz every 1.5 minutes for its first week adrift, and thereafter one day in three to save power and reduce tracking charges. NOAA satellites carrying CLS-Argos systems pass over at least six times per day and fix the drifter positions to better than 1 km. The drifters were manufactured by Moonraker Technology Pty Ltd in Hobart.

The satellite images in this paper came from Advanced Very High Resolution Radiometers (AVHRRs) aboard NOAA satellites, and the data were received at stations at Alice Springs and Darwin. The images were processed to give sea-surface temperature estimates, using the method of McMillin & Crosby (1984), and remapped to a standard cartographic projection (Nilsson & Tildesley 1986). The images include a 1°x1° latitude–longitude grid, and they have a temperature scale along their tops. Clouds appear white in the images.

RV *Franklin's* instrumentation included a Neil Brown CTD, Turner fluorometer, and Niskin bottle rosette for water sampling, a thermosalinograph, and a RD Instruments 150 kHz Acoustic Doppler Current Profiler (ADCP) that continuously measured current profiles, using a bottom-track mode when the water depth was less than ~300 m and the Global Positioning System (GPS) in the deeper waters. Note that the ship's ADCP cannot measure currents in the lowest 15% of the water column. This is because of side lobes in the transducer radiation patterns. We use practical salinity units (International Oceanographic Tables 1981) and Universal Time; Australian Eastern Standard Time is UT + 10 hrs. The ship's weather station recorded wind speed and direction and corrected these for ship's speed and direction.

The paths followed by RV *Franklin* on the two voyages are shown in figure 1. The stations occupied on FR3/97 were repeated on FR10/97 as weather permitted. A change from bad to good weather near the end of FR10/97 allowed a transect to be done from King Island.

The moored 150 kHz ADCPs were mounted in floats several metres above the bottom at the 100 and 200 m isobaths off western Tasmania. These instruments measured currents from near the bottom to 15 m and 30 m from the surface respectively.

RESULTS

Satellite-tracked Drifters

Of 13 drifters, one was released off eastern Tasmania in August 1991; three were released off the same coast in May 1992; three off western Tasmania in July 1992; three off southern Tasmania in November 1992; and three off western Tasmania in January 1994. We will not discuss all the drifter tracks in detail — rather, while making general comments about all the drifters, we will concentrate on drifters that were released off western Tasmania and later summarise our findings in a simple schematic for the near-surface currents in summer and winter.

The drifters released off western Tasmania (fig. 2) revealed a southward current on the continental shelf in both winter and summer. The drifters that were beyond the shelf generally did not detect this current. In *winter* the drifters from the west were carried up the eastern Tasmanian continental shelf, sometimes as far as Schouten Island, before coming under the influence of the East Australian Current and being swept SSE. In *summer* the drifters only went as far as the southern end of Tasmania before encountering the southern extension of the East Australian Current. This carried them southward and into eddies. Figure 2 shows, also, how one drifter from the east moved westward to the south of Tasmania and eventually was entrained into the Zeehan Current. Several other drifters behaved similarly.

Eleven of the 13 drifters left Tasmanian waters to follow meandering paths tending ENE towards New Zealand,

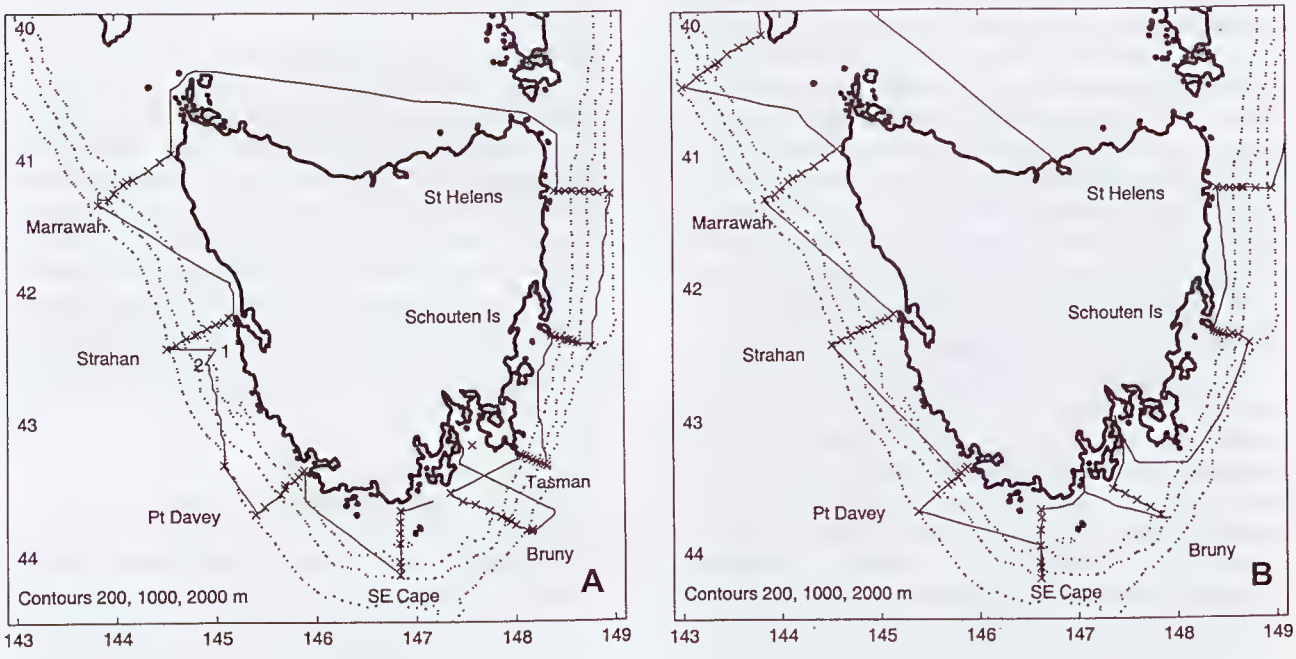


FIG. 1 — The station positions and the paths followed by the RV Franklin: (A) 19–27 *March and (B) 1–9 December 1997. The locations of the two moored Acoustic Doppler Current Profilers are marked as 1 and 2 on the 100 m and 200 m isobaths respectively.*

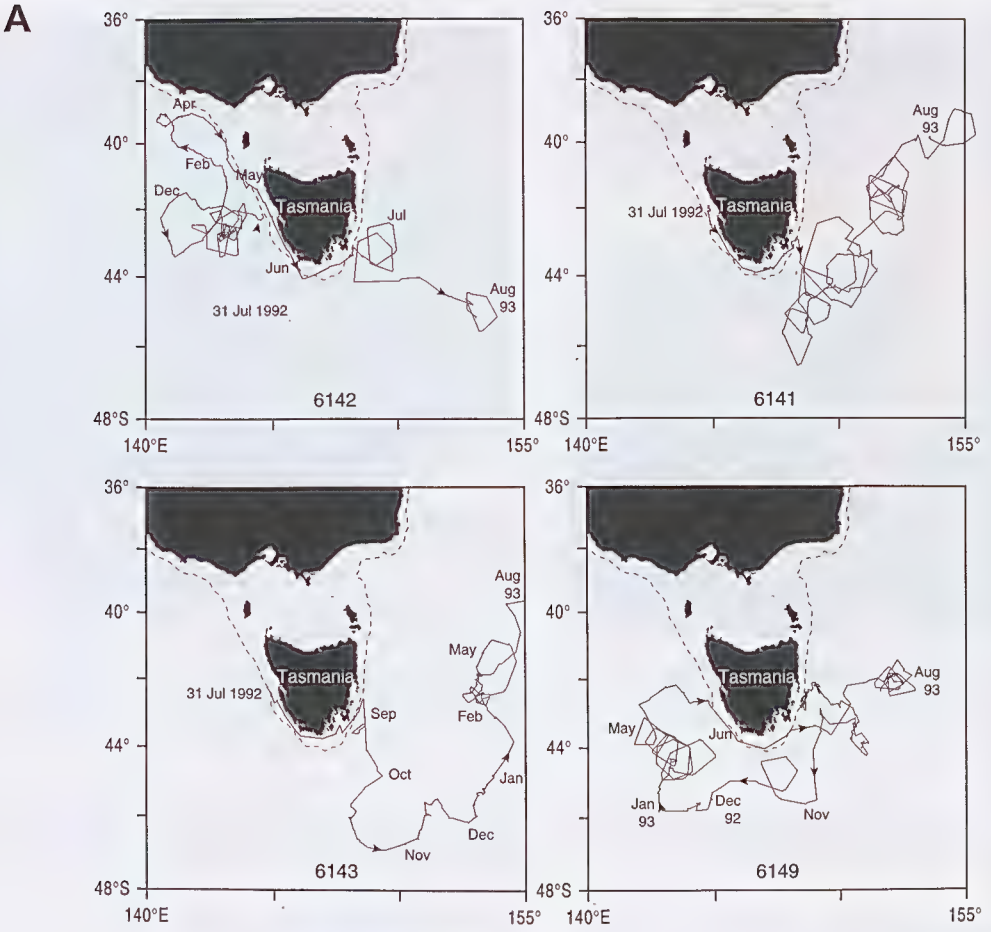


FIG. 2 — (A) The tracks of four drifters, showing the influence of the Zeehan Current in taking continental shelf water from western to eastern Tasmania in winter. This flow reaches almost to Schouten Island on the east coast before part of it is entrained into the East Australian Current. (B) The tracks of three drifters released off western Tasmania in summer, showing the Zeehan Current to be flowing on the continental shelf at that time as well as in winter. The Zeehan Current only reached southern Tasmania before being entrained into the East Australian Current and swept ~200 km southward.

probably south of the Subtropical Front, and four examples are shown in figure 3. These were all within 200 km of New Zealand before their electronics failed 16, 20, 22 and 32 months respectively after they were released. These travel times will be relevant when considering the likelihood of colonisation of New Zealand by Tasmanian marine creatures.

Winter and Summer Satellite Sea-surface Temperature Images

Satellite sea-surface temperature images reflect the behaviour of the drifters. A winter image (fig. 4A) shows the Zeehan Current as warm water (~12°C) coming southward down the western Tasmanian continental shelf, around to eastern Tasmania, and then northward at least as far as Maria Island before encountering the East Australian Current. Note the eddies to the west of King Island, the offshoots of warm water off southwestern Tasmania, and the extensive cold regions in southern and eastern Bass Strait.

The summer image (fig. 4B) shows the Zeehan Current reaching southern Tasmania before being entrained into the East Australian Current, which overshoots 200 km past the island. The image is within the period covered by the drifter tracks in figure 2B and it delineates the same warm eddy as the drifters.

Observations from the RV *Franklin* in March and December 1997

Not all data can be included here. We discuss sections of temperature and salinity from the CTD and north–south and east–west velocity components from the ADCP off St Helens, Bruny Island and Strahan (fig. 5A–C). The ADCP data showed the East Australian Current in the open ocean off St Helens and Bruny Island to have speeds of 0.3 to 0.4 ms^{-1} southward. On the St Helens line, the surface waters of the East Australian Current were salty and warm (>35.4 psu, >16°C) and they extended in across the shelf, in keeping with the 0.1 ms^{-1} westward current component detected by the ADCP. There was a northward component to the flow at the upper continental slope and over the shelf.

The warm salty East Australian Current waters were only evident at the extreme seaward end of the Bruny Island line in March. The current on the shelf was to the northeast and it carried low salinity water (<35 psu) from southern and, perhaps, western Tasmania. We suggest that this was the extension of the Zeehan Current and that it had been freshened by terrestrial runoff from western Tasmania.

Off Strahan in March, the southward-flowing Zeehan Current prevailed over most of the line and reached speeds of 0.2 ms^{-1}. The salinity structure was complicated because of the influence of low salinity outflow from Macquarie Harbour at the surface; a core of high salinity water (35.2 psu) in the thermocline that extended across the shelf at 50–80 m depth, perhaps from the Great Australian

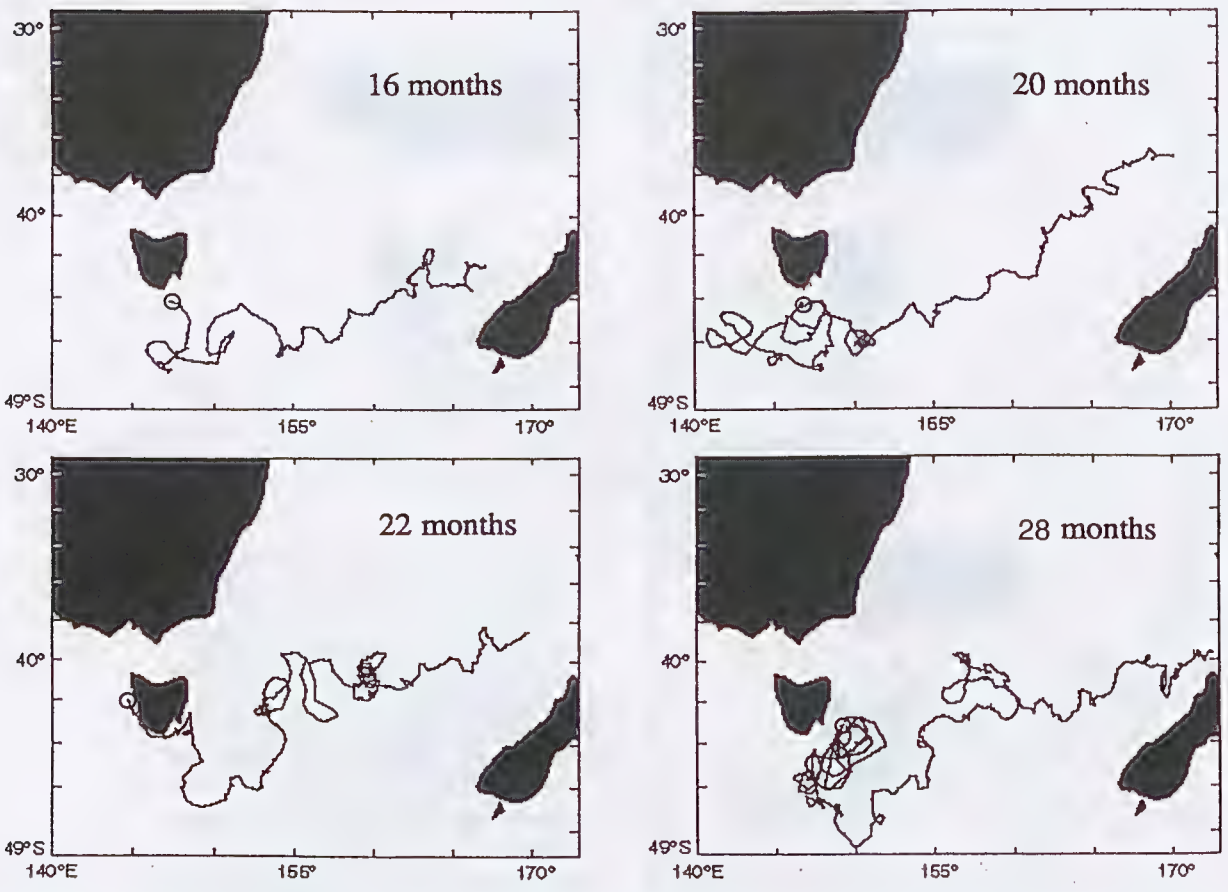


FIG. 3 — The paths of four (of 11) drifters that went from various Tasmanian release sites (small circles) over towards New Zealand. Their lifetimes were: November 1992–March 1994; November 1992–July 1994; July 1992–May 1994; and August 1991–December 1993.

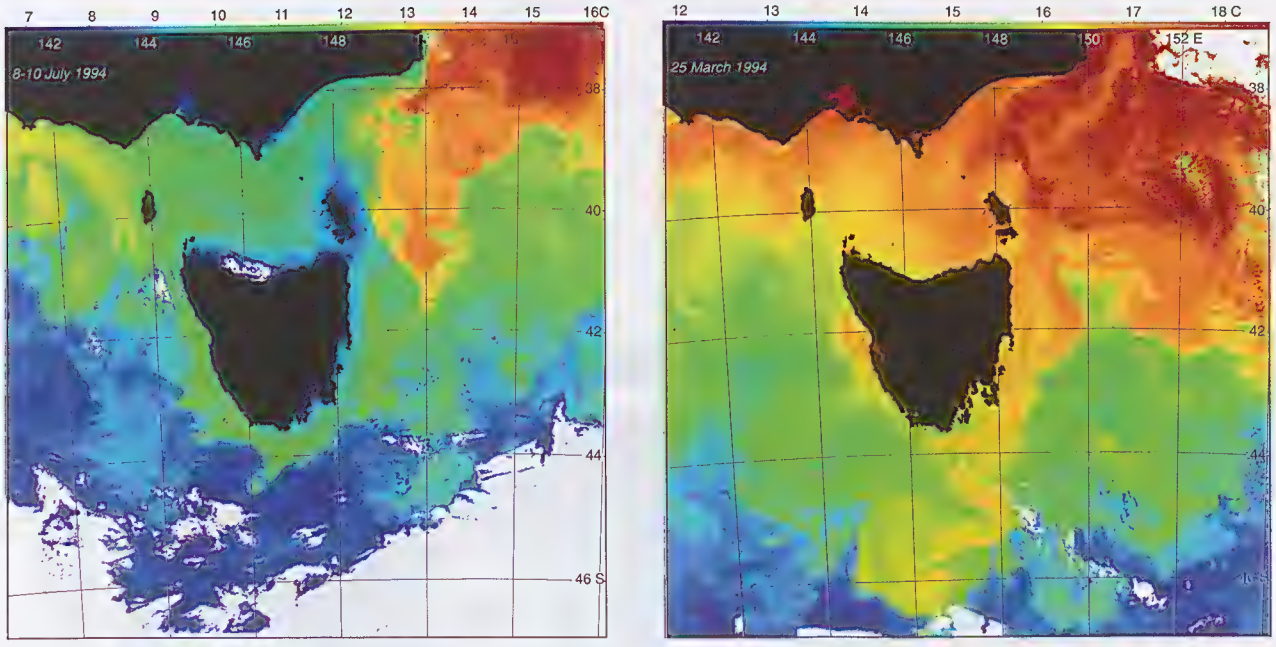


FIG. 4 — Winter (A) and summer (B) satellite sea-surface temperature images from the NOAA11 satellite. Red is warm ranging through blue, which is relatively cold. The temperature scale is across the top of the images. Clouds are white.

Bight; and a stratum of relatively high salinity water (>34.9 psu) between 80 and 170 m depth that extended into the shelf from the open ocean. The temperature structure was less informative, although the thermocline could be seen to be stronger and shallower than off St Helens. The Macquarie Harbour plume did not have a noticeable temperature signature and so would not be detected by infrared sensors on satellites.

The conditions along the St Helens line in December were somewhat surprising in that, while the upper waters of the outer shelf and open ocean were salty and warm, typical of the East Australian Current, the currents there were northeastward — with a strong subsurface core of 0.4 ms^{-1} northward near the upper continental slope. We conclude that this was a meander on the edge of a stronger flow of East Australian Current water. On the shelf, the flow was southwestward, and this appears to have driven upwelling of relatively cool and fresh water (<15°C, <35.2 psu) to the surface on the inner shelf.

Inclement weather stopped the December Bruny Island line near the shelf edge. The currents there were south-eastward at 0.4–0.5 ms^{-1}. Curiously, there was no evidence of the warm salty waters of the East Australian Current. On the inner shelf (excluding very near the shore) the flow was northeastward as in March, bringing low salinity water (<35) from southern and western Tasmania.

The December Strahan line revealed a narrower and slightly stronger Zeehan Current flow than in March. It was strongest at the upper continental slope and extended deeper than the 300 m depth range of the ADCP. As in March, the salinity section revealed the Macquarie Harbour outflow; a salty (>35.1 psu) intrusion of, perhaps, Great Australian Bight water on the continental shelf; and a stratum of relatively salty water (>35 psu) in the upper waters of the open ocean that reached into the shelf. The thermocline was much weaker than in March.

The ADCPs Moored at the 100 and 200 m Isobaths near Strahan

The current vector time series (fig. 6) present measurements averaged over the top, middle and bottom thirds of the water column, neglecting the uppermost 15% (David Griffin, pers. comm.). The shelf edge (200 m) instrument recorded a persistent southward flow that peaked in June. Northward flows were rare. The shelf instrument (100 m) also showed predominant southward flow in May/June, but the flow was variable at other times. Of interest, the temporal features of the currents recorded at both instruments showed some consistency through the water column.

The bottom temperatures recorded by the instruments had broad peaks in the winter months. Taken together, the current and temperature records suggest the southward flow in winter of a deep mixed current that is stronger at the shelf edge than nearer to shore. The variability in temperature was larger at the shelf edge instrument, perhaps because of meandering of the current. The largest variability occurred in early July, when the current at the outer site had decreased to very low values, supporting the suggestion of meandering.

The time series of wind resolved along the coast, negative southward, suggests that there may be a loose relationship between it and the current at the 100 m site. We would expect a stronger relationship nearer the coast.

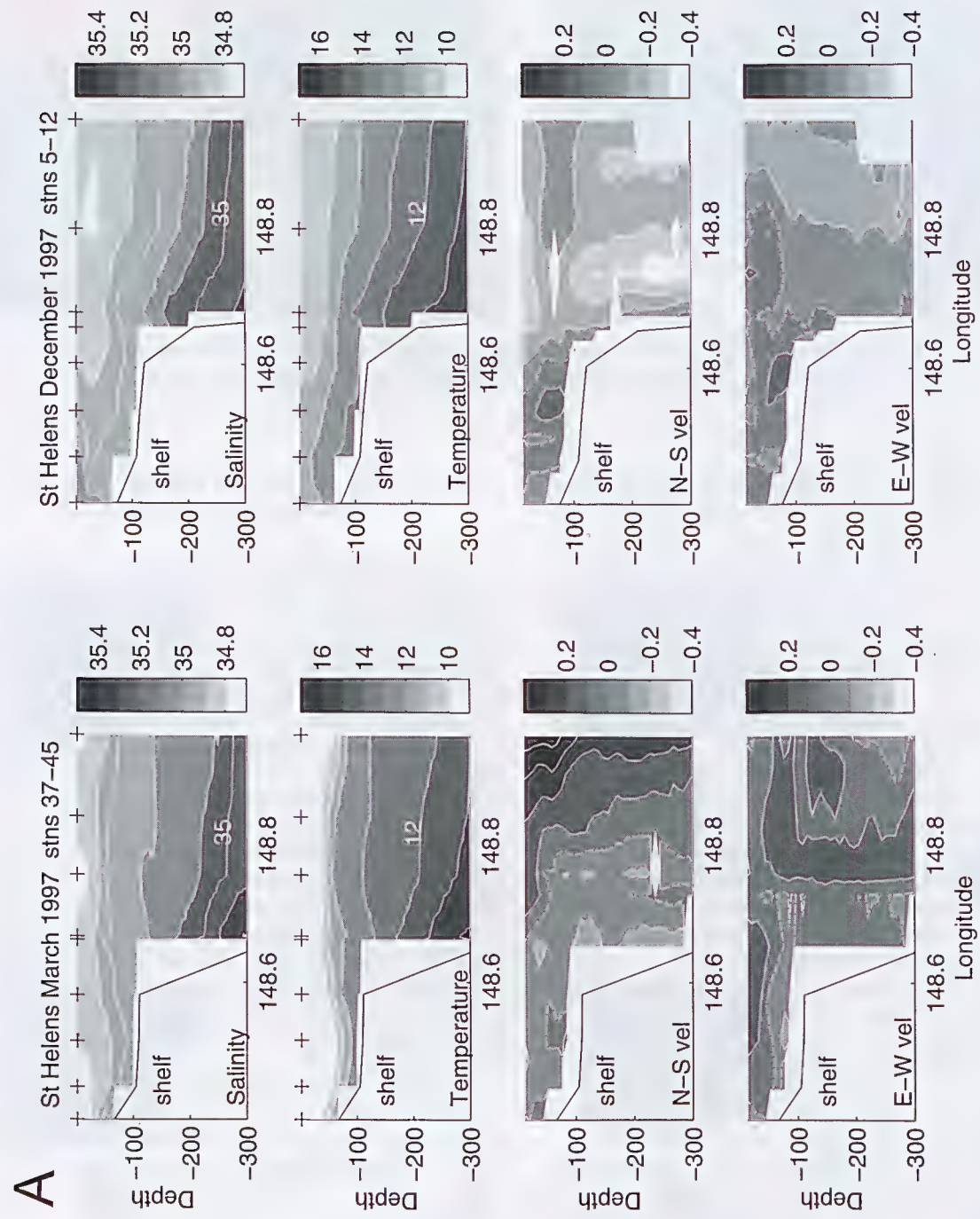
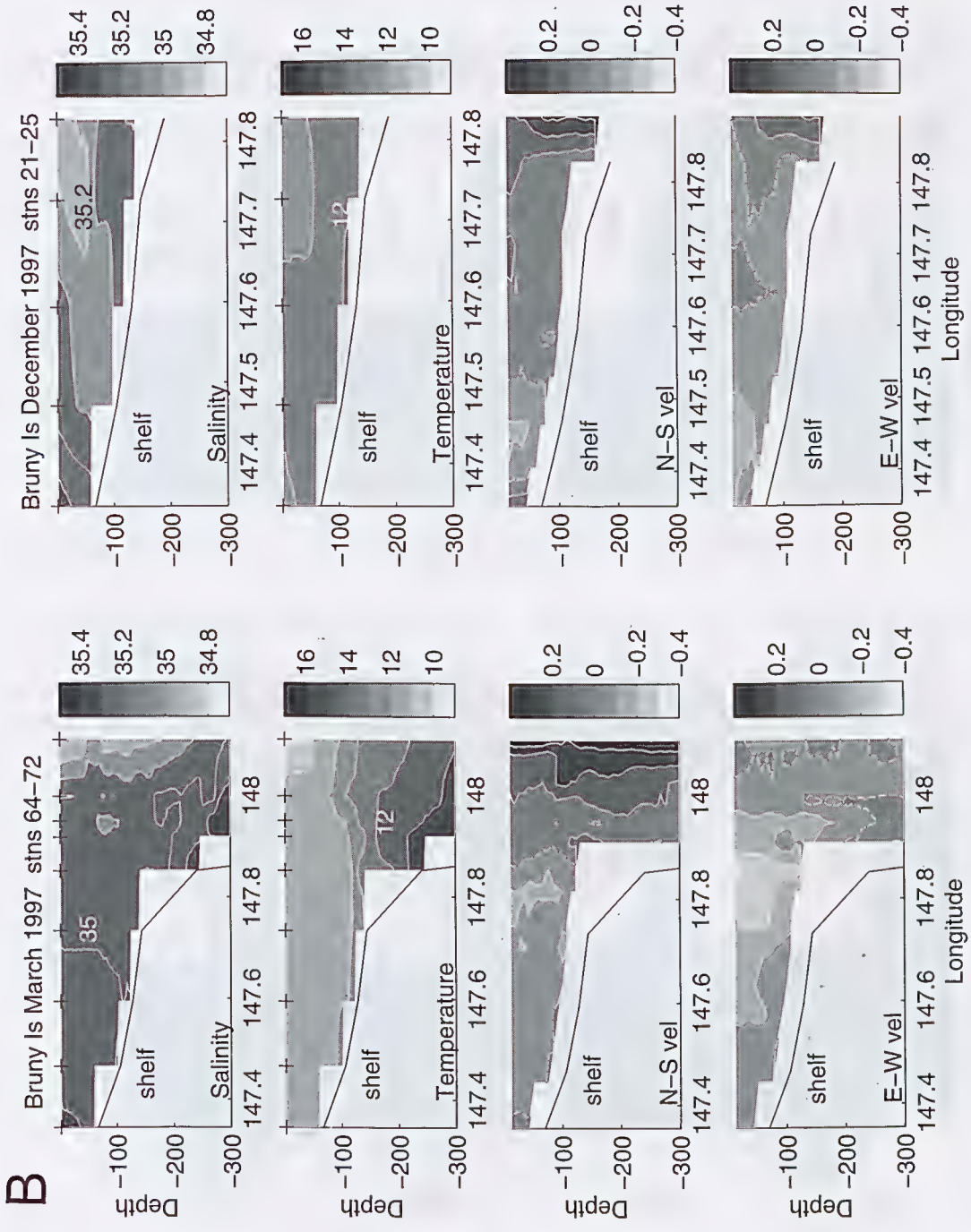
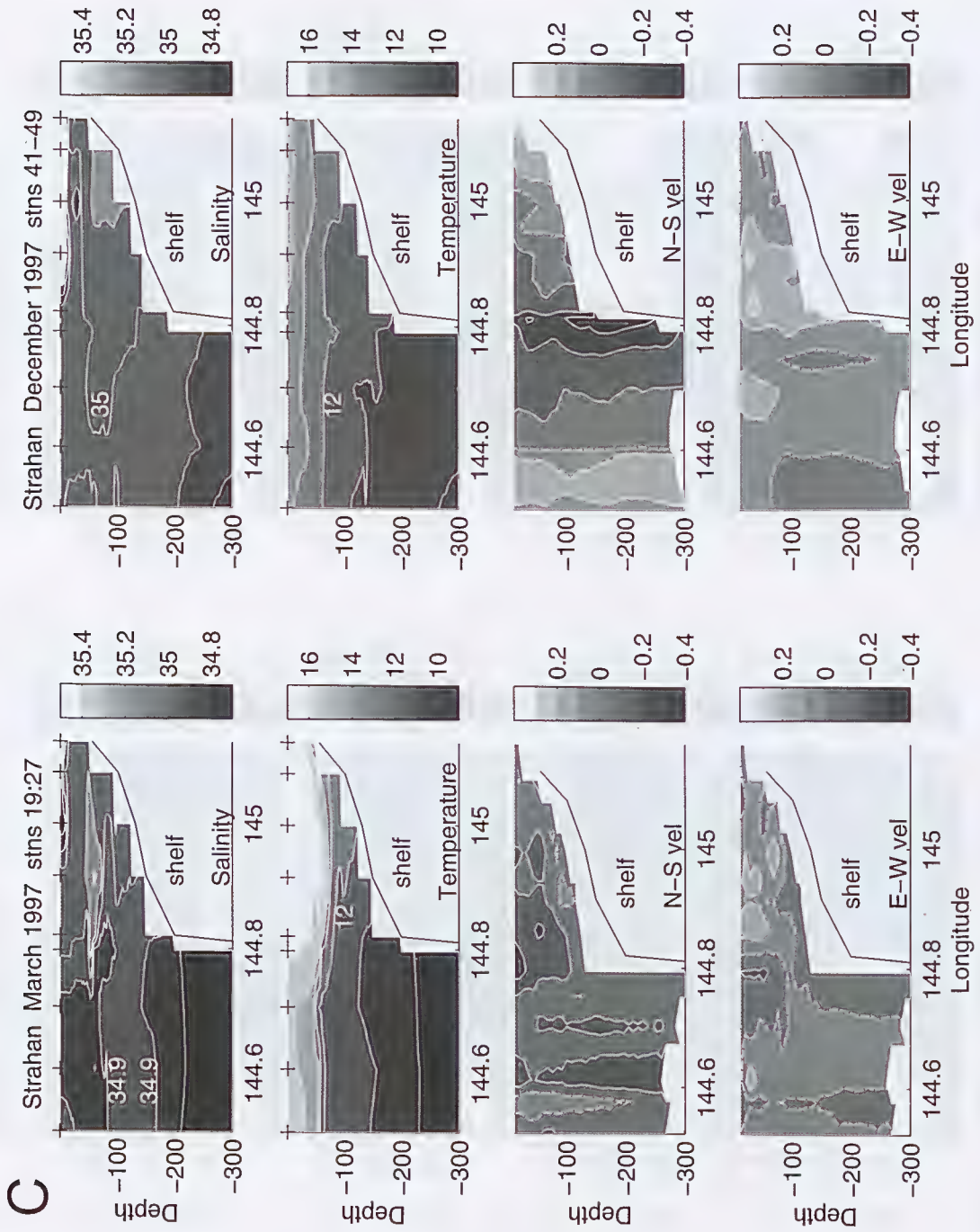


FIG. 5 (A–C) Sections of salinity, temperature, and north–south and east–west current components down to 300 m at the St Helens, Bruny Island, and Strahan lines in March and December 1997. Northward and eastward flow in the current plots are positive (lighter shading) and the dashed lines mark zero.


B
Bruny Is March 1997 stns 64–72
Bruny Is December 1997 stns 21–25
Depth
shelf
Salinity
Temperature
N–S vel
E–W vel
35
35.2
12
Longitude
147.4
147.5
147.6
147.7
147.8
148
−100
−200
−300
35.4
35
34.8
16
14
12
10
0.2
0
−0.2
−0.4


C
Strahan March 1997 stns 19:27
Strahan December 1997 stns 41–49
Depth
Longitude
shelf
Salinity
Temperature
N–S vel
E–W vel
34.9
35
12
144.6
144.8
145
−100
−200
−300
35.4
35.2
35
34.8
16
14
12
10
0.2
0
−0.2
−0.4

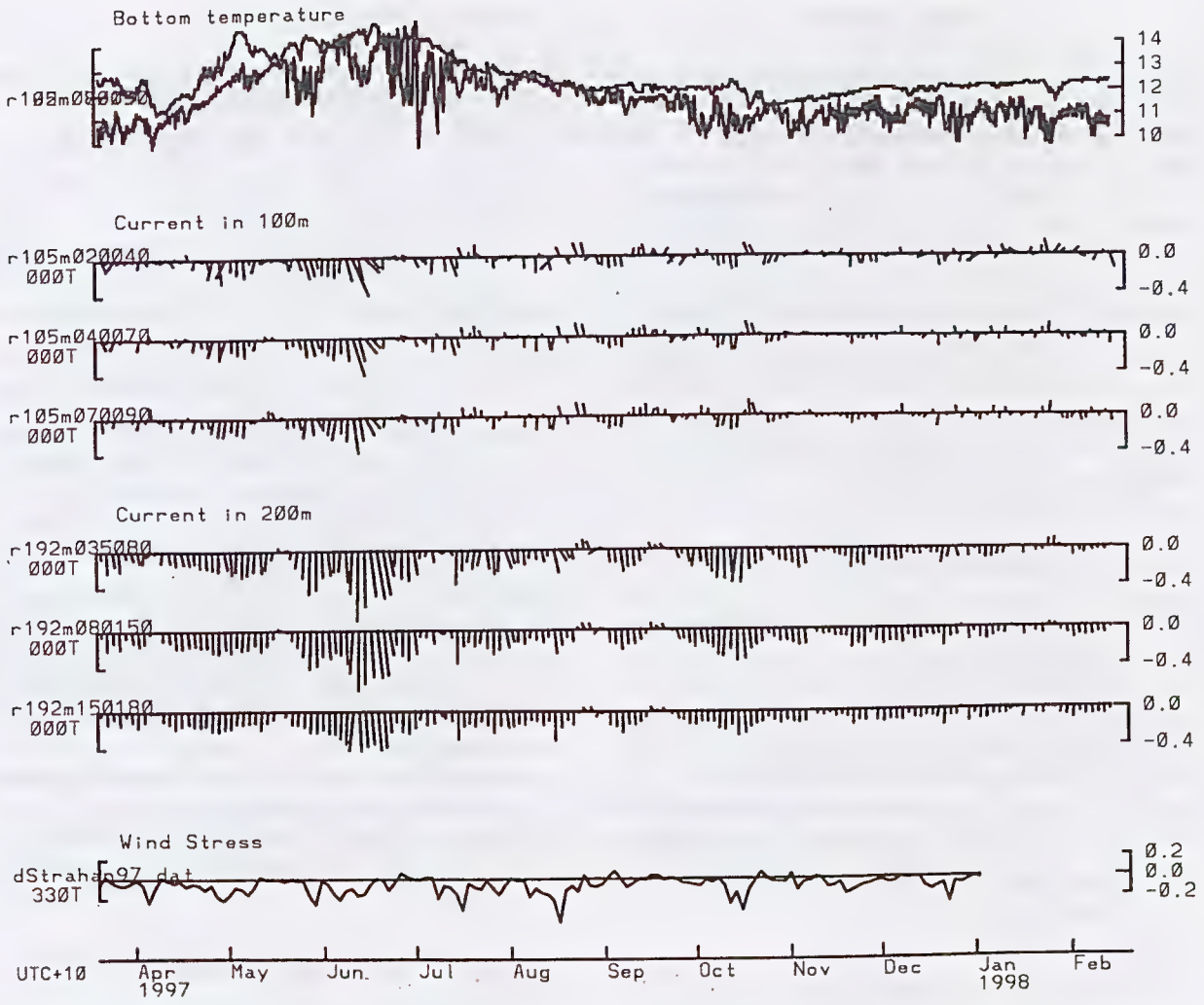


FIG. 6 — Bottom temperatures and current vector time series measured with Acoustic Doppler Current Profilers moored near the bottom at the 100 m and 200 m isobaths off Strahan, western Tasmania; winds resolved parallel to the coast, negative southward. The currents at each of the sites are averaged over the top, middle and bottom thirds of the water column.

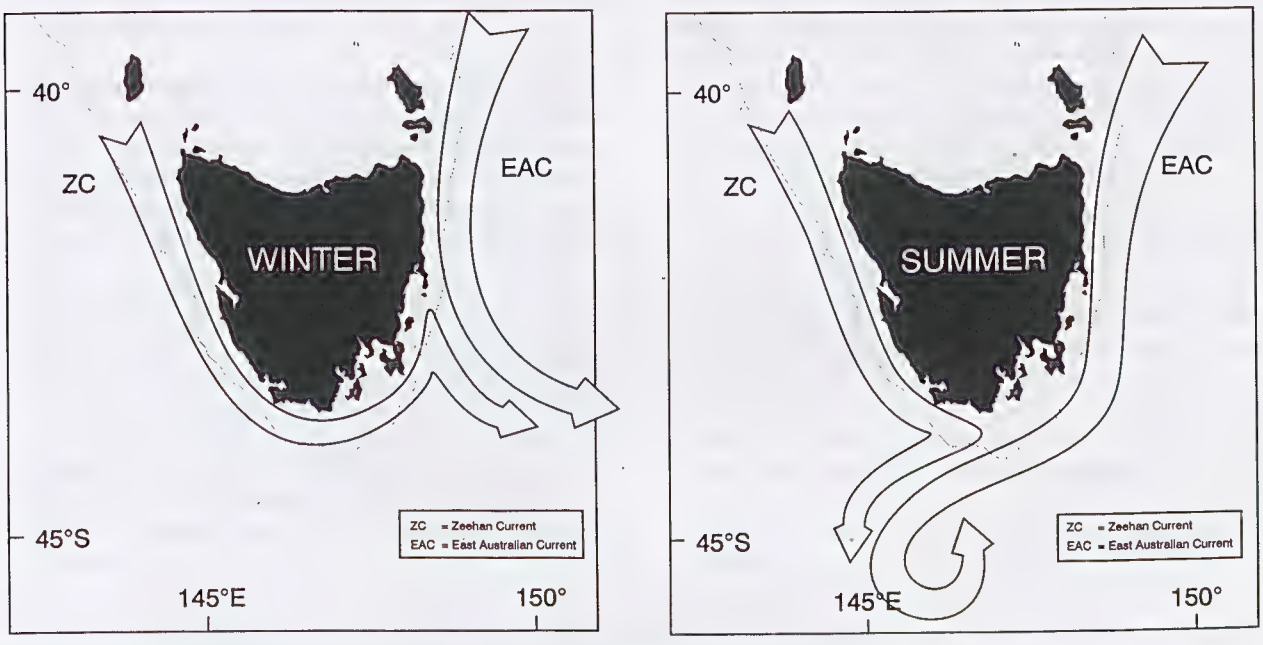


FIG. 7 — Schematic pictures for winter and summer showing the Zeehan Current off western Tasmania and its interaction with the East Australian Current.

CONCLUSION

The interplay of the Zeehan and East Australian Currents that first emerged from the drifter work is summarised in the winter and summer schematic diagrams in figure 7. These appear to be supported by the additional data types presented here. We have used the name Zeehan Current to mean the current on the outer half of the western continental shelf and upper slope, even though Baines *et al.* (1983) referred only to the slope when they coined the name; they had no data on the shelf. Along southeastern Tasmania, the Zeehan Current appears mainly confined to the shelf as a relatively low salinity feature. The winter maximum of the Zeehan Current that appears in our moored current measurements agrees with the winter maximum that was observed with moored current meters by Lyne & Thresher (1994) in the same region.

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(accepted 29 August 1999)

SEABED MAPPING ON AUSTRALIA'S SOUTHERN MARGIN: BASELINE INFORMATION FOR SCIENCE AND MARINE MANAGEMENT

by H.M.J. Stagg, N.F. Exon & P.J. Hill

(with one table and seven text-figures; figures 4 and 6 in colour)

STAGG, H.M.J., EXON, N.F. & HILL, P.J., 2000 (31:v): Seabed mapping on Australia's southern margin: Baseline information for science and marine management. *In* Banks, M.R. & Brown, M.J. (Eds): *TASMANIA AND THE SOUTHERN OCEAN. Pap. Proc. R. Soc. Tasm.* 133(3): 31–40. ISSN 0080–4703. Australian Geological Survey Organisation, Canberra, ACT, Australia.

In ratifying the United Nations Convention on the Law of the Sea in 1994, Australia took responsibility for a marine jurisdiction that is more than 1.5 times the area of the landmass. While ownership of offshore resources provided under UNCLOS bestows certain rights (including exploitation), it also carries a range of obligations, including the protection and preservation of the marine environment. In order to fulfil these obligations, there is a key need for the acquisition and interpretation of baseline scientific information that will support the sustainable use and management of marine resources.

The most critical baseline information required is the detailed depth and shape of the seafloor and the nature of the shallow substrate, particularly in high-use areas. Such information underpins the activities of virtually all government, industry and academic sectors working offshore, including petroleum and minerals, fisheries and mariculture, engineering, defence, transport, tourism and environmental management. Knowledge of the seabed is also critical for the issues of multiple sequential land use to be addressed offshore. The current state of such knowledge is extremely variable, with the highest quality 3-D seabed mapping data being available over only about 5% of the Australian marine jurisdiction.

Certain basic data sets should be available to all organisations and individuals working in the marine environment. Description and discussion of the seabed mapping component of acquiring those data sets on the southern margin of Australia form the basis of this paper. Priorities for seabed mapping are suggested, e.g. the southeastern and southwestern margins of the continent.

Key Words: seabed mapping, swath mapping, marine science, Australian southern margin, Law of the Sea, Australian marine jurisdiction, marine zone management.

AUSTRALIA AND THE LAW OF THE SEA

When Australia ratified the United Nations Convention on the Law of the Sea (UNCLOS) in 1994, it assumed the responsibility for a marine jurisdiction that is 1.5 to 2 times the area of onshore Australia (fig. 1, table 1). Within this jurisdiction (the Australian Marine Jurisdiction or AMJ), a number of zones have legal significance. Of these zones, two are particularly relevant here.

- *The Australian Exclusive Economic Zone* (AEEZ) extends 200 nautical miles from the Territorial Sea baselines. Within the 8.6 million km^2 of this zone around Australia and its island territories, Australia has sovereign rights to explore and exploit, and conserve and manage the natural resources of the water column, the seabed and the subsoil.

- *The Legal Continental Shelf* includes the AEEZ and those areas which can be considered to be natural prolongations of the continent extending beyond the AEEZ. Within those areas extending beyond the AEEZ, Australia has sovereign rights over the natural resources of the seabed (including organisms attached to the seabed and the subsoil, but not over the water column. The area of the AMJ beyond the AEEZ is in the range of 3.3–3.7 million km^2, or about half the area of onshore Australia.

Once a nation ratifies UNCLOS, there is then a ten-year time span to allow that nation to acquire and interpret the data that defines those areas beyond the EEZ, and submit its case to the UN Commission on the Limits of the Continental Shelf. In Australia's case, the deadline for submission is late 2004.

While ownership of offshore resources provided under UNCLOS bestows certain rights (including rights to exploit resources), it also carries a range of obligations to preserve and protect the marine environment. For a nation to be able to fulfil these obligations and also sustainably use and manage the resources, there is a key need for certain basic data sets to be available to all organisations and individuals working in the marine environment. Description and discussion of the seabed mapping component of acquiring those data sets on the southern margin of Australia form the basis of this paper, in which we will

- discuss the relevance of seabed mapping to many marine sectors;

- outline some of the technical aspects of modern seabed mapping, particularly the technique known as swath-mapping;

- summarise some of the major results of seabed swath-mapping on Australia's southern margin; and

- outline the priorities for future seabed mapping around Australia.

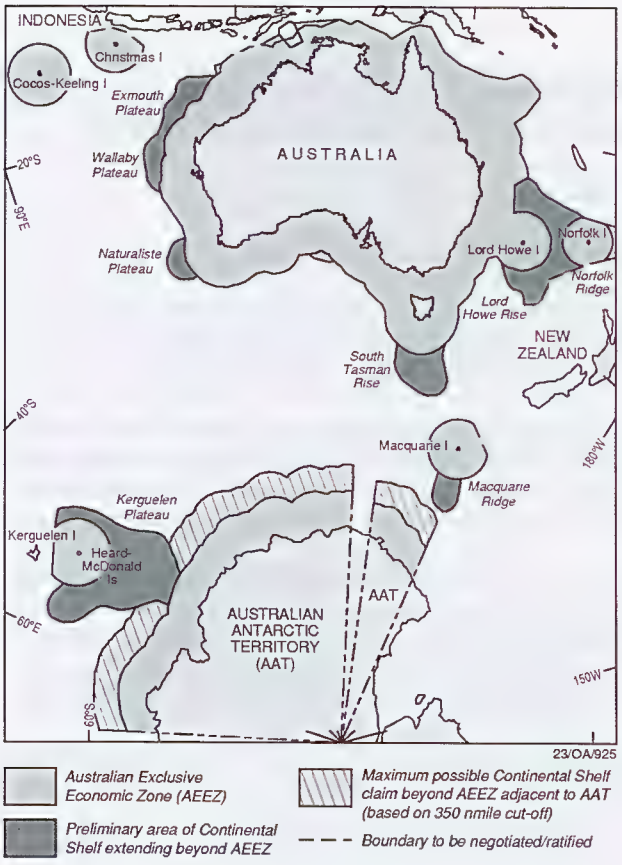

FIG. 1 — Australian jurisdictional zones under the United Nations Convention on the Law of the Sea.

TABLE 1
Approximate areas of the elements of the Australian Marine Jurisdiction

	Area ($\times 10^6$ km^2)
Australian landmass	7.8
Continental shelf (geomorphological)	2.4
Australian Exclusive Economic Zone (AEEZ)	
Australia + Lord Howe overlap	6.7
Australia + island territories	8.6
Australia + island territories + Australian Antarctic Territory	11.1
Extended Continental Shelf beyond AEEZ	
South to AAT (60°S)	3.3
Around AAT beyond EEZ	3.7
Total Australian Marine Jurisdiction	
Australia + territories, south to AAT	11.9
Australia + territories, south to EEZ around AAT	12.3
Australia + territories + EEZ around AAT	14.8

SECTORAL ISSUES IN THE AUSTRALIAN MARINE JURISDICTION

In 1997, the Australian Geological Survey Organisation (AGSO) convened a marine geoscience planning workshop with the aim of determining national priorities for a seabed mapping program in the AMJ that incorporated the needs of most of the principal sectors working offshore (Stagg *et al.* 1997). The marine sectors involved were:

government bodies – including those dealing with living and non-living resource policy and management, environment, marine jurisdiction, "land" use, defence and hydrography;

industry – including companies with involvement in petroleum exploration and production, minerals exploration and production, seabed engineering (petroleum production platforms, pipelines, communications), tourism;

universities and other research organisations – including individuals and groups conducting basic research into geological processes, environment and climate change, pharmaceuticals and biotechnology.

Most of the sectors have their main interests directed at the water column, seafloor, or shallow substrate (fig. 2). Only the petroleum exploration, government policy and research sectors stand out as having a level of focus directed significantly below the seabed in the deeper crust.

Some of the more important of these sectoral interests in the seabed and shallow substrate are discussed below.

Marine jurisdiction

Definition of the outer limit of Australia's Legal Continental Shelf under UNCLOS requires detailed knowledge of the depth and shape of the seabed in deep waters (Symonds & Willcox 1989). In several areas, the limit of Australia's jurisdictional claim, which must be submitted to the United Nations by late 2004, will be defined on the basis of detailed bathymetry.

Petroleum exploration and production

The design and construction of petroleum production facilities (including platforms and pipelines) is strongly dependent on the depth, nature and physical properties of the seabed which must support such structures.

In the 1990s, the popular and trade press have reported several examples where inadequate technical knowledge has imposed major costs on exploration and development projects. These include the problems associated with the setting of piles for the Goodwyn gas production platform, which incurred major additional constructional costs as well as a start-up delay of several months; the dangerous exposure of a gas pipeline through cyclone-induced sediment mobility, which required remedial work at a cost of about $80 million; and the damage sustained to a jack-up oil exploration rig which collapsed when the supporting seabed gave way while drilling was taking place in South Australian waters.

Fisheries

The habitats of many commercial fisheries are controlled by the detailed seabed topography and substrate. These fisheries, which can be very fragile components of marine ecosystems, are often poorly understood and managed. For example, the

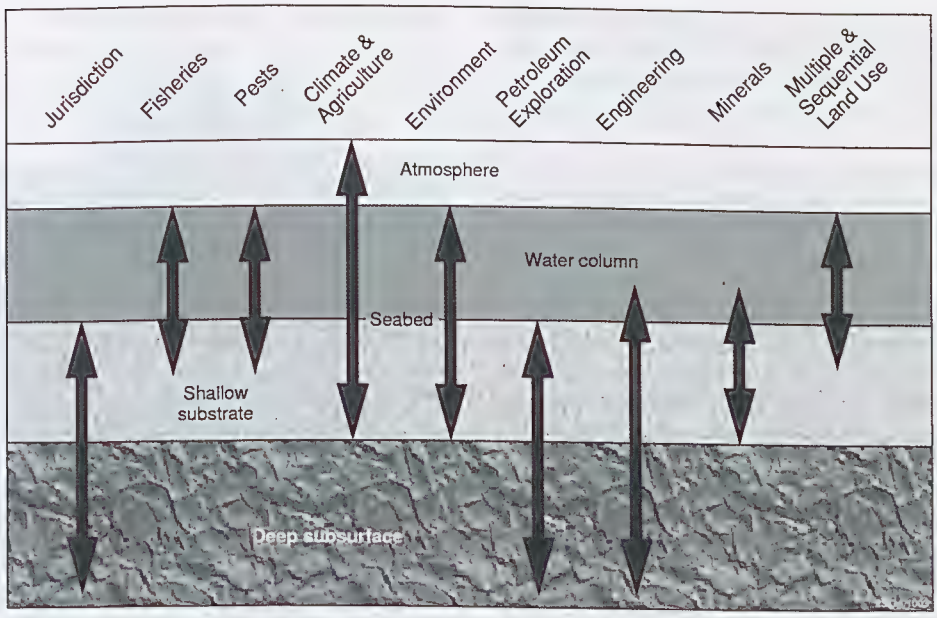

FIG. 2 — The four linked regimes of the marine environment and their relevance to key marine sectors.

existence of the valuable orange roughy fishery, south of Tasmania, is largely dependent on the presence of a particular seabed form, with associated benthic flora and fauna (Koslow & Exon 1995, Koslow 1997).

Climate change

Geoscience can make a major contribution to society by helping agricultural planning, through the understanding of long-term climatic change. The study of sediment cores from lakes or the deep ocean can extend our knowledge of climatic variability back many millions of years (Harris *et al.* 1999a). The higher the sedimentation rate, the better the accuracy and definition. The study of growth phases in cores from living large colonial corals provides an exceedingly accurate record of climatic changes over the last few hundred years (Barnes & Lough 1989). Fossil corals may eventually extend this record back a few thousand years (McCulloch *et al.* 1994). These studies extend the databases of climatic modellers back much further than the historical records they are more used to dealing with, thus improving their models.

The 1997 planning workshop identified the critical need for detailed mapping of the depth, shape and nature (sediment type, physical properties etc.) of the seafloor throughout the marine zones, particularly in high-use areas. These needs form the focus of this paper. The associated issue of which organisation/s should be responsible for the collation, storage and dissemination of bathymetric data and other information is also fundamental.

SEABED MAPPING — TECHNICAL ISSUES

Seabed mapping involves the integration of two basic techniques: determination of the seabed topography, through direct measurement of the water depth and the shape of the seabed, and "ground truthing" the nature of the seabed by sampling the rocks and sediments. While a considerable amount of work has been done in this field around Australia, particularly in the past 30 years, the current state of knowledge of the seabed in much of the AMJ is comparable to the state of onshore knowledge in the 19th century.

Seabed Topography

For most of the past few hundred years, water depth and seabed topography have only been measured immediately beneath a vessel while it is underway, initially by lead-line and more recently by single-beam echo-sounder. Such mapping is necessarily slow, and the maps which are prepared from such data are frequently inaccurate, as they require the interpolation of data between tracks that may be hundreds of metres to tens of kilometres apart.

However, in the early 1990s, three new techniques became available that have improved our knowledge of seabed topography by orders of magnitude — satellite-measured gravity and the derived predicted bathymetry; Laser Airborne Depth Sounding (LADS); and ship-board "swath-mapping" (also known as multibeam mapping). While satellite-predicted bathymetric data are invaluable for defining the gross form of the seabed in the world's oceans, particularly in remote areas, the spatial resolution is limited to about 3 km, even in the most modern data sets. LADS is being used extensively by the RAN Hydrographic Office for mapping bathymetry to depths of about 50 m in areas that are particularly hazardous to navigation We will not consider these techniques further in this paper.

Seabed swath-mapping can be carried out either by towed sidescan sonar systems or by hull-mounted multibeam sonar systems (fig. 3). Exon & Hill (1999) have reviewed these systems and their relative merits. Systems of both types are capable of mapping in great detail in shallow water, or in reduced detail in deeper water. Although sidescan sonar initially produced only backscatter imagery, and multibeam systems produced only digital bathymetry, those systems are progressively becoming dual purpose.

With sidescan sonar, a sound pulse (a "ping") is emitted in a narrow beam at right angles to the ship's track (Flemming 1976). Echo arrival times and amplitudes are

recorded to produce a line scan on a plotter, and a map of a swath of seabed is built up from successive pings as the ship moves. As the transmission geometry changes with distance across-track, a slant-range correction is usually applied to produce a plot which has been geometrically corrected. The sonar image particularly shows variations in seabed reflectivity (and hence hardness), roughness and slope. Some sidescan systems now have a bathymetric capability, with both sidescan images and bathymetry recorded simultaneously. Bathymetry across the swath is determined by measuring phase differences of acoustic arrivals on a pair of transducer arrays on each side of a towfish. The phase difference gives the direction of the backscattered return; combined with the arrival time, this yields both depth and position (Exon & Hill 1999).

In very simplistic terms, multibeam sonar systems can be thought of as a large number of conventional single-beam echo-sounders with their beams set in a fan across-track (Hill *et al.* 1995). Multibeam systems have transmitting and receiving transducer arrays mounted at right angles on the hull, with the transmit array(s) aligned along the fore–aft axis of the ship. The transmit beam is narrow alongship and wide athwartships. Individual receivers (162, in the case of the Simrad EM12D shown in fig. 3), which have a narrow athwartships focus, span the transmit sector, so that each received beam has a small footprint (sampling area) on the seafloor. The beams are electronically stabilised to counter roll and pitch of the ship. Detection of the seabed in the weak signal from the outer beams is achieved by comparing the phase of the returns at the two rows of transducers in the receive array. Seabed backscatter images can also be produced from the beam-formed signals of a multibeam system, and these can be directly superimposed on bathymetric contour maps (Hill *et al.* 1995).

One of the strengths of swath-mapping systems is that the technique can be used in the full range of water depths from a few metres to the deepest bathyal depths. Shallow-water systems typically transmit at frequencies of more than 100 KHz and can be installed on vessels of only 10 m length, while deep-water systems transmit at around 12 KHz and are typically installed on ocean-going research vessels. The "footprint" and swath width of shallow and deep-water systems show similar variations, with the footprint ranging from less than a metre square to 50 m^2 or greater, and the swath width ranging from a few tens of metres to as much as 20 km.

Systematic swath-mapping is a powerful tool for addressing both ancient and modern geological processes. Where the surficial sediment cover is thin, swath-mapping can image strata that crop out at the seabed and, hence, reveal the "tectonic grain" and the distribution of structures within and adjacent to a sedimentary basin. Such information can provide framework information of fundamental importance to hydrocarbon exploration and complements the relatively widely spaced seismic profiles which are normally the prime source of tectonic information (Gardner *et al.* 1991). Where the surficial sediments are relatively thick, analysis of bathymetric and back-scatter data can provide a detailed picture of the distribution and reflectance of modern sediments, and hence of the oceanographic and geologic conditions that have produced this distribution. When ground-truthed by seabed cores, this information can be important to the production and development of Australia's offshore hydrocarbon resources,

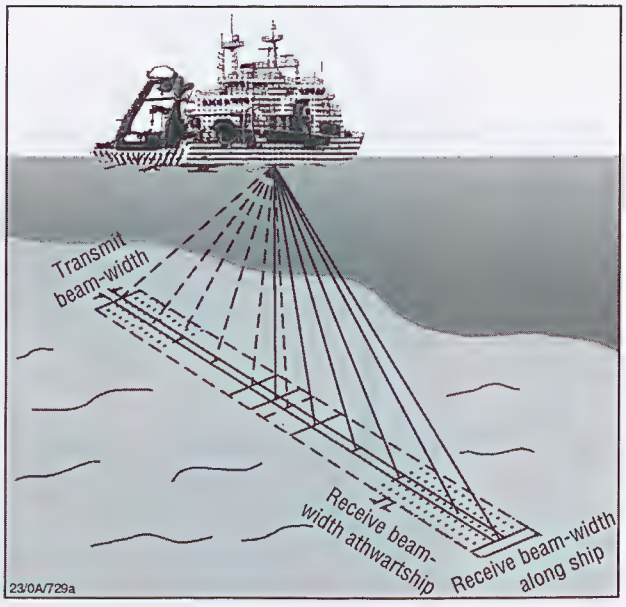

FIG. 3 — Schematic of Simrad EM12D hull-mounted multi-beam swath-mapping system showing the acoustic beam configuration (after Hill et al. *1995).*

to future offshore minerals mining (including construction materials) and in the mapping of benthic habitats.

An important issue with regard to seabed swath-mapping is that of the large volumes of data that are rapidly acquired, and their access and archiving. Typically, a modern swath-mapping system acquires at least a gigabyte of data per day of surveying. While post-processing reduces this data volume, the reduction is only of the order of about 50%.

Seabed Sampling

The second component of a seabed mapping program is the ground-truthing of the sonar images through sampling of the shallow substrate. A large amount of seabed sampling has been carried out in the past 30 years by a number of organisations, including AGSO, RAN Hydrographic Service, universities and industry.

While a large amount of sediment data has been acquired, it is only in the past few years that serious attempts have been made to assemble the information in a form that could be accessible to a national seabed mapping program. Development of the AUSEABED database by the Ocean Sciences Institute (Jenkins & Searle 1997, for description; Jenkins 1997, for maps) and AGSO's MARS database are attempts to collate the available information into a form that is accessible by modern technology. However, there is currently no national sample repository (or network of repositories), which means that it is difficult, in many cases, to access the original samples.

The majority of the vast number of seabed samples that have been collected have only sampled the shallowest few metres of sediment. In fact, many of the samples collected by the RAN Hydrographic Service have only come from the shallowest few centimetres. Sampling below these surficial depths (say, below 5 m) requires more sophisticated techniques than those which are generally available. Cores up to 40 m long can be taken in soft deep-sea sediments by

giant piston corers, such as those on the French research vessel *Marion Dufresne*, which took such cores on the South Tasman Rise and elsewhere in 1997 (Nees *et al.* 1998). Such coring systems are of little value where hard rocks outcrop at the seabed or are shallowly buried.

The Ocean Drilling Program (ODP 1996) and its predecessor the Deep Sea Drilling Project (DSDP) are capable of taking continuous or near-continuous cores in soft sediments, sedimentary rocks and igneous rocks in almost any water depth greater than 100 m, down to 2000 m below the seabed, although few holes have yet gone deeper than 1500 m. Since 1971, a number of DSDP and ODP drilling legs have been carried out in the oceans around Australia, including DSDP Legs 21, 26, 27, 29 and 90, and ODP Legs 119 and 120 (Kerguelen Plateau and Prydz Bay), 122 and 123 (Exmouth Plateau, Gascoyne and Argo Abyssal Plains), 133 (northeast Australia), and 182 (Great Australian Bight). Further drilling legs are scheduled in 1999–2000 on the South Tasman Rise and in Prydz Bay, Antarctica. The disadvantage of this tool is that it is expensive and samples a very limited number of locations.

A consortium based at the University of Sydney has built a Portable Remotely Operated Drill (PROD). PROD is designed to recover up to 100 m of core from research or industry vessels in water depths of up to 2000 m. Such a sampling technique can fill the gap between conventional gravity, piston and vibrocoring, and ODP or industry exploration drilling.

EXAMPLES OF SWATH-MAPPING SURVEYS

There have been two main phases of seabed swath-mapping around Australia since the inception of this type of work in the early 1980s. In the first phase (1983–89), combined GLORIA (ultra-long range sidescan sonar) and SeaBeam (multibeam sonar) surveys were carried out by HMAS *Cook* off northeastern Australia (Johnson *et al.* 1992), New South Wales (Jenkins & Lawrence 1990), canyon systems south of the mouth of the Murray River (von der Borch & Hughes Clarke 1993) and part of the southern coast of Western Australia. As the swath-mapping technique was then in its infancy, these data sets are of limited value when compared to the data which can now be acquired.

The second phase of swath-mapping commenced in 1994, when AGSO mapped 160 000 km^2 of seabed along 800 km of the Macquarie Ridge, north and south of Macquarie Island (Coffin *et al.* 1994). This survey used the HMR1, a towed wide-angle imaging system developed by the Hawaii Institute of Geophysics, which was deployed from the AGSO research vessel *Rig Seismic*. The HMR1 produces high-quality side-scan imagery, but its bathymetric resolution is only about half that of modern multibeam echo-sounders.

Since the Macquarie Ridge survey, a further three surveys have been carried out in Australian waters; all of these have been carried out on foreign vessels of opportunity, and all have been focussed on the southern margin. These surveys are:

- **the *Tasmante* survey** (1994) south and west of Tasmania, using the French vessel *L'Atalante* (Exon *et al.* 1994, Hill *et al.* 1995, Exon & Crawford 1997);
- **the East Tasmania survey** (1997), which encompassed the continental margin of Tasmania and Victoria from south of Hobart to the northern side of the Bass Canyon using the US research vessel *Melville* (Hill *et al.* 1998, Exon *et al.* 1999); and
- **the MARGAU survey** (1998) off southwest Australia using the French research vessel *Marion Dufresne* (Royer *et al.* 1998).

The major results of the *Tasmante* and East Tasmania surveys provided valuable examples of the quality of data which can now be produced and their multidisciplinary, cross-sectoral value. Figure 4 shows the topography of the Tasmanian region and incorporates the swath-mapping data from both of these surveys. The effect of the swath-mapping data can be seen in the high degree of detail on the Tasmanian margins, on the western flank of the South Tasman Rise and east of Bass Strait.

Tasmante Survey

The *Tasmante* survey was carried out for AGSO with the French research vessel *L'Atalante*. The main aim of the survey was to map in detail the South Tasman Rise and the west Tasmanian margin and to use the results to refine our understanding of the geological framework of the region, particularly the breakup of Australia and Antarctica in the Late Cretaceous and Cainozoic. *L'Atalante* is equipped with a Simrad EM12D system, a 162-beam sonar system with a maximum swath coverage of 150°, enabling a strip of seafloor more than 20 km wide to be mapped at a single pass in moderate water depths.

The geological results of this survey have been discussed in a number of papers (Exon & Hill 1999, Exon *et al.* 1996, 1997, Hill *et al.* 1995, 1997) and will not be discussed in detail here. Suffice it to say that the swath-mapping data, in conjunction with reflection seismic data that were recorded concurrently, have led to a revised and much more detailed interpretation of the geological framework of the region, including deep-water sedimentary basins that may be prospective for hydrocarbons at some stage in the future.

The value of seabed-mapping to the non-geoscience marine sectors was well illustrated by the *Tasmante* survey. Areas south, east and west of Tasmania are host to major demersal fisheries for orange roughy and blue grenadier. Because the fishermen seek to run their trawls just above the seabed, the high-quality *Tasmante* bathymetric maps of the seabed have generated a great deal of interest. Prior to the release of detailed maps of the two fisheries areas south and west of Tasmania, AGSO consulted widely with other Commonwealth agencies about conservation questions, concerning not only the fish stocks but also the organisms growing on numerous seamounts in the region. The Southeast Trawl Association agreed that newly discovered deeper seamounts (fig. 5) should be the subject of a fishing moratorium while research was carried out into their natural resources (Koslow & Exon 1995), and a 370 km^2 interim Commonwealth Marine Protected Area was declared. CSIRO is carrying out a three-year study of the impact of trawling on seamounts and the conservation value of the protected area. Koslow (1997) reported that the seamounts

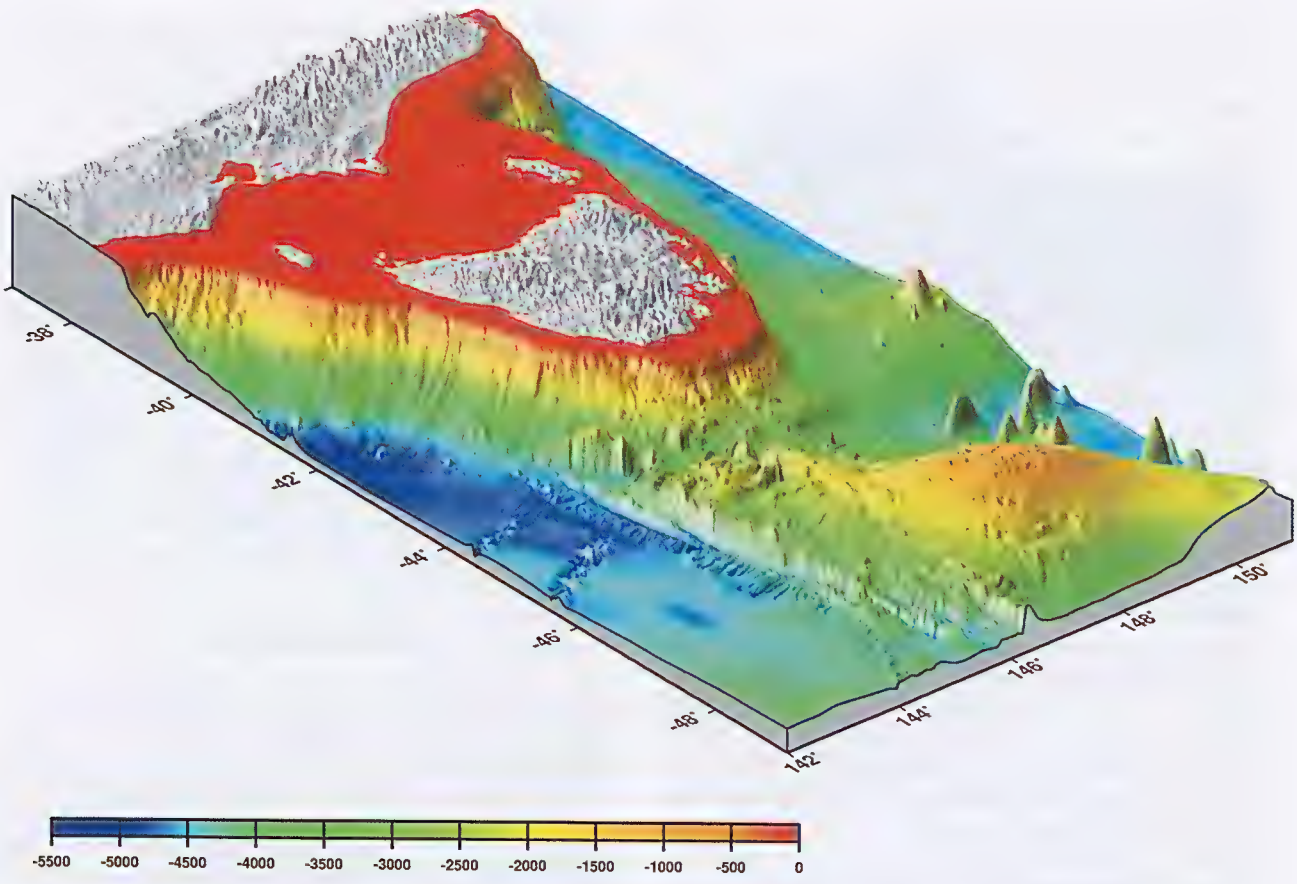

FIG. 4 — Perspective view of the topography of the Tasmanian region. Regional bathymetry from the global ETOPO5 digital data set, supplemented in Bass Strait by data from the RAN Hydrographic Office. Detailed bathymetry west, south and east of Tasmania, and east of Bass Strait was recorded by swath-mapping on AGSO surveys. Note the change in resolution near the edge of the abyssal plain southwest of Tasmania where swath-mapping and ETOPO5 data have been merged.

support a diverse fauna dominated by a colonial stony coral, *Solenosmilia variabilis*, and that the fauna is highly endemic with numerous new species.

East Tasmania Survey

In 1997, the 85 m Scripps Institution of Oceanography research vessel *Melville* mapped the seabed on the continental margin of east Tasmania and at the eastern end of Bass Strait in a cooperative project with AGSO. The *Melville* is fitted with a SeaBeam 2000, a 121-beam sonar system with a swath coverage of 120°. The maximum swath width is about 3.4 times the water depth, and about 20 000 km^2 of the margin were surveyed in eight days of surveying (Hill *et al.* 1998).

The aims of the cruise were to determine the morphology and seabed character of selected areas, to provide data for tectonic, basin and sedimentological studies (including surveying a jarosite dumping site southeast of Hobart – Harris *et al.* 1999b), to aid the fishing industry, and to provide critical information for future geoscience surveying. A specific objective was to map the structure of bedrock outcrop on the eastern margin of an inferred sedimentary basin beneath the upper continental slope off the Freycinet Peninsula.

Figure 6 is a perspective view to the northwest of the continental margin east of Bass Strait and illustrates the

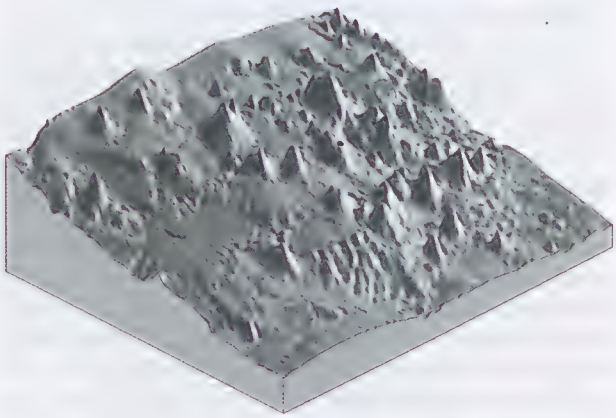

FIG. 5 — Field of seamounts on the upper continental slope, south of Tasmania recorded by swath-mapping. This image measured approximately 40 km^2. These seamounts, many of which were not known prior to the swath-mapping, are found in water depths of 900-2300 m. They typically stand about 400 m above the adjacent seabed and are several kilometres across. The summits of some of these seamounts are the natural habitat of the adult orange roughy.

quality of this data set. The Bass Canyon is a large embayment 100 km across that is floored by an axial ESE-trending, 10–15 km wide axial trough. This trough has probably acted as a conduit for clastic sediment being transported to the deep Tasman Basin since eastern Australia separated from the Lord Howe Rise at about 80 Ma (Hill *et al.* 1998). The adjacent shelf beneath the eastern Bass Strait is generally flat and less than 100 m deep, and is covered by sandy sediments.

The shallow-water part of the survey area is significant in that it lies adjacent to oil and gas fields, such as Esso's Blackback Field being developed in the Gippsland Basin, and is also an important fishing ground. The seafloor here is characterised by a steep upper continental slope with closely spaced, erosional channelling (fig. 6). These channels were probably cut during glacial lowstands when abundant sediment was shed from an exposed continental shelf, eroding the slope as it was transported into the canyon. Alternatively, the gullies may have been initiated by slope failure (also during lowstands) of unconsolidated sediments, and subsequent headward erosion.

The upper slope channelling feeds into a broad semi-circular amphitheatre that is ~60 km across and forms the upper reaches of the Bass Canyon (fig. 6). The surface of this amphitheatre is deeply incised by three major tributary canyons and a number of smaller channels. These funnel sediment from the shelf into the incised axial chasm. The larger canyons are typically 1 km wide and up to several hundred metres deep. The trends of the canyons show abrupt changes of direction in places, probably caused by their being deflected by faults or more resistant strata in the underlying Gippsland Basin. Abandoned meander plains adjacent to the canyons, but at higher levels, show that the path of downslope sediment flow has migrated in time. Large, high-relief canyons and ridges are found on the northern wall of the central chasm and on the steep continental slope facing the Tasman Abyssal Plain. These features are probably sculptured in basement or older sediments of the Gippsland Basin and are structurally controlled.

The axial trough is 60 km long and is bounded to the north and south by very steep inner canyon walls 1000 m high. The 7–8 km-wide floor of the trough is relatively flat and dips gently eastwards. Sediments transported down the trough debouch at about 4000 m depth and spread onto the abyssal plain via a network of distributary channels and levees (Hill *et al.* 1998).

Examination of the new topographic data in conjunction with existing seismic profiles over the Bass Canyon complex shows that submarine erosion has exposed sections of almost the entire Gippsland Basin sequence back into the Early Cretaceous strata, as well as basement rocks (Hill *et al.* 1998: fig. 5). Based on the new maps and images, numerous suitable dredge and core sampling sites in the canyons have been identified for geological sampling which may provide new information of value to the petroleum exploration and development industry.

NATIONAL PRIORITIES FOR SEABED MAPPING

In 1999, the Australian government released its Marine Science and Technology Plan (MSTP Working Group 1999), designed to address the marine science and technology needs for the ensuing five to 15 years. The plan contains three programs — understanding the marine environment; using and caring for the marine environment; and infrastructure for understanding and utilising the marine environment — and a total of 28 objectives within these programs. Program 1, Objective 2 was defined as

> *To map the form and nature of the seabed of Australia's Marine Jurisdiction.*

Within this objective, several priorities and strategies were identified as relevant to a program of seabed mapping around Australia. These included

> *Implementation of a national swath-mapping program and seabed data digitisation program, on a priority basis determined by the regional marine planning process;*

and

> *Develop and implement a systematic national program to swath-map the seabed, and to sample the seabed, substrate and benthic biota of the AMJ …*

While the importance of a seabed mapping program (particularly swath-mapping) was seen as a key element of the success of the plan, it was also noted that Australia currently has very limited capacity for carrying out this style of work. In deep water, off the morphologic continental shelf, such work can currently only be undertaken using foreign vessels of opportunity, mainly of French or US registry. The RAN Hydrographic Service is currently (1999) commissioning two new ocean-going hydrographic vessels and their attendant survey motor launches which will be equipped with swath-mapping systems capable of working to depths of 300–500 m. However, these vessels are dedicated to hydrographic surveying to ensure safety of navigation, and it is likely that their availability to carry out any systematic mapping on the morphologic shelf for other purposes will be extremely limited.

As part of the process of developing the Marine Science and Technology Plan, a number of priority areas was proposed in the draft plan (MSTP Working Group 1998). To some extent, these priorities have been superseded with the release of the Australian Oceans Policy (Commonwealth of Australia 1998) and the final MSTP. We therefore suggest that the following areas (fig. 7) are the highest priorities in the short to medium term (1–5 years).

Priority 1

Southeast Australia

This region is considered to be the highest priority because the work will have direct relevance in diverse and important sectors of the marine economy. The area is also the first region of Australia for which a Regional Marine Plan will be developed, as outlined in the Oceans Policy (Commonwealth of Australia 1998). Part of this area has already been covered by the *Tasmante* and East Tasmania surveys referred to above. Geologic information will increase our understanding of the framework of southeast Australia, with consequent spin-offs for petroleum exploration in producing (Gippsland Basin) and frontier areas (Otway and Sydney Basins, Lord

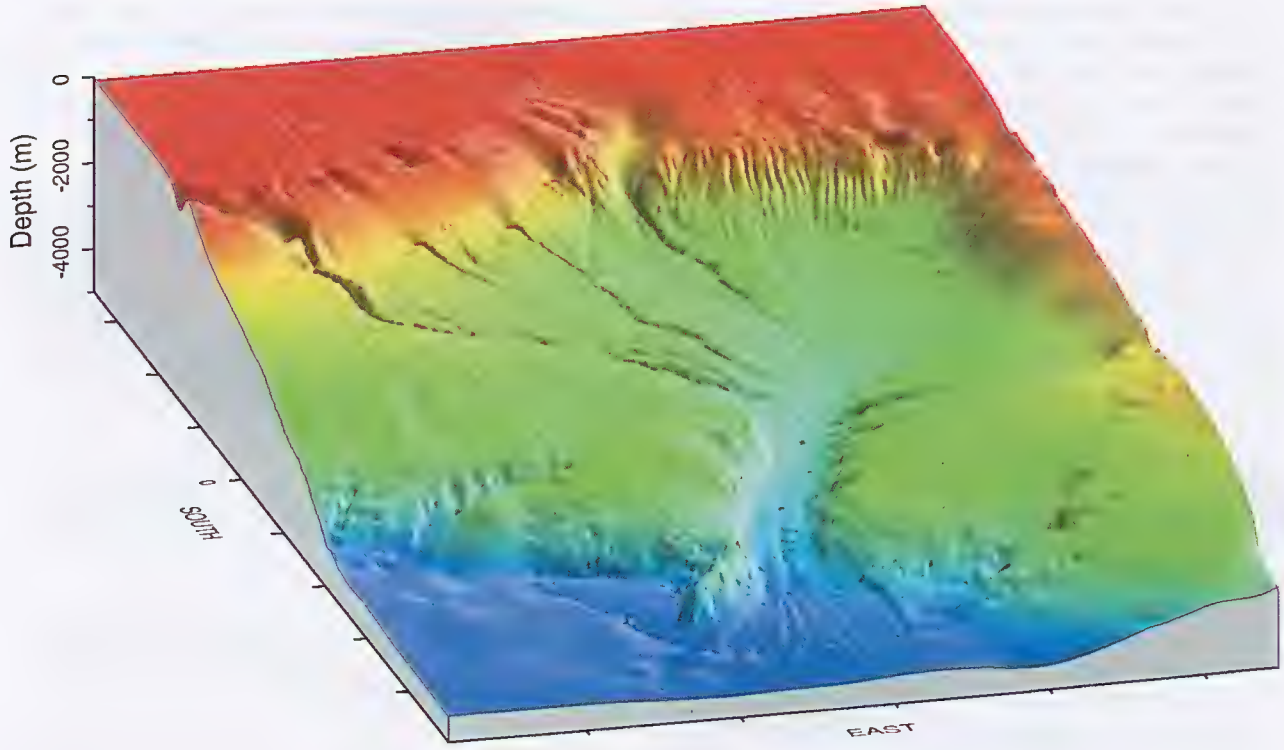

FIG. 6 — Perspective view of Bass Canyon, looking northwest from the Tasman Sea (after Hill et al. *1998). Horizontal scale is indicated by the tick marks at 20 km intervals. The image was generated from high-resolution swath-mapping data, with infill at the edges of the image provided by older, conventional bathymetric data from multiple sources. The water depths range from about 4400 m in the Tasman Basin, in the foreground, to less than 200 m deep on the continental shelf, in the background.*

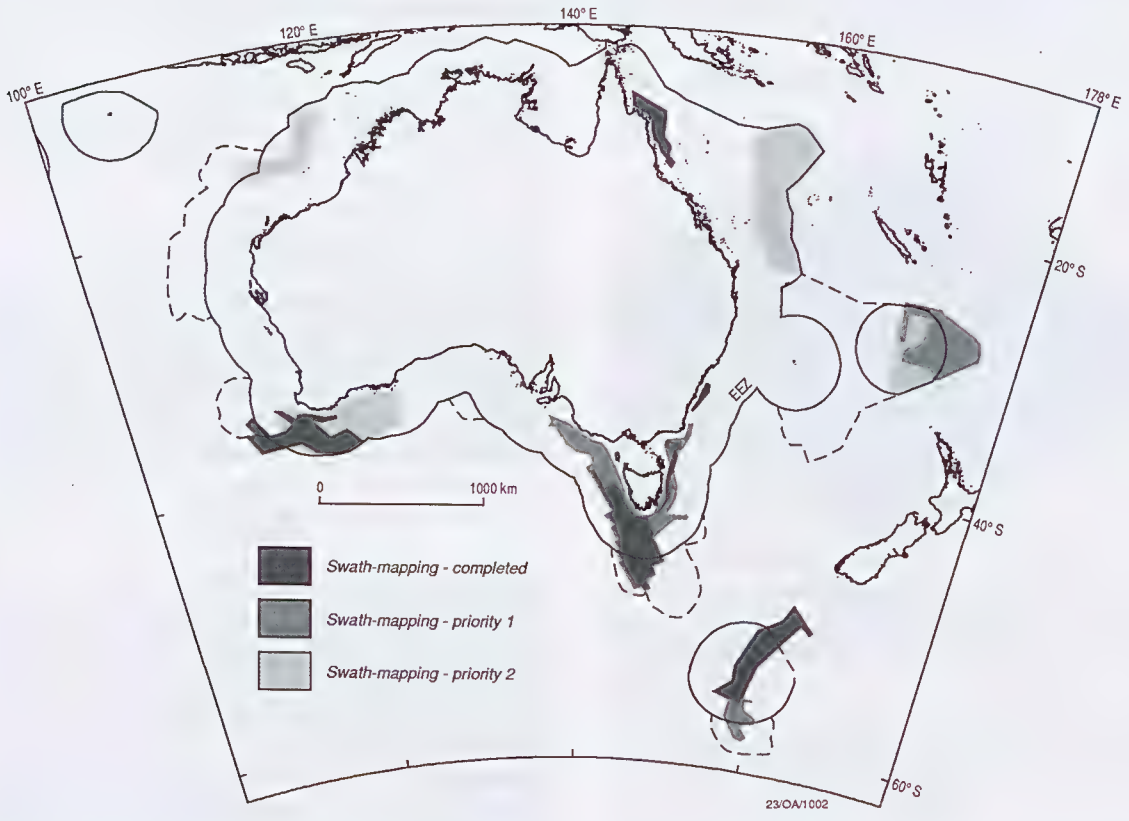

FIG. 7 — Areas around Australia which have previously been swath-mapped, and priority areas for future swath-mapping.

Howe Rise). The region also contains important commercial and recreational fisheries, for which bathymetric and substrate information will be valuable to the determination of habitats and biodiversity. Australia's major industrial and population concentrations are also located in southeast Australia; urban and rural discharge and water/sediment quality are therefore major issues, particularly on the continental shelf.

Three Kings Rise / Norfolk Basin

The extent of the Legal Continental Shelf beyond the EEZ around Norfolk Island is uncertain. Bathymetric data may well enable Australia's claim in this complex area to be considerably extended. This work is now scheduled to be carried out in late 1999, using the French research vessel *L'Atalante*.

Macquarie Ridge

The extent of the Legal Continental Shelf south of Macquarie Island along the Macquarie Ridge remains to be defined; detailed bathymetric data are sufficient to establish this claim. In addition, as detailed bathymetry data are required to assist in the definition of the Macquarie Marine Protected Area (MPA), there is a requirement to fill in the gaps that were left after the 1994 swath-mapping survey.

Southwest Australia

The tectonic fabric of this area, which is readily apparent in bathymetric data because of the thin surficial sediment cover, is one of the keys to understanding the formation of Australia's southern margin, with consequent impacts for petroleum exploration in the frontier basins of the region, from the southern Perth Basin, through the Great Australian Bight to the Otway Basin. The work required here will complement the cooperative French-Australian MARGAU survey, which was carried out in 1998. Swath-mapping of the upper slope also has the potential to provide information of value to commercial fisheries in the region.

[Since this paper was written, most of the Priority 1 areas have been surveyed by swath-mapping. In late 1999–early 2000, surveys were carried out in the following areas: northeast Lord Howe Rise; Three Kings Rise/Norfolk Basin; the environs of Lord Howe Island; Macquarie Ridge and southeast Australia (extension and infill of previous surveys); and the Benthic Protection Area in the central Great Australian Bight.]

Priority 2

Norfolk Ridge

Norfolk Ridge is a component of the major oceanic plateau, ridge and basin system that was attached to eastern Australia until the mid-Cretaceous. Swath-mapping of the region should enhance our limited understanding of the tectonic fabric of the Lord Howe Rise region, a major area of medium- to long-term hydrocarbon potential. Potential fish habitats and biodiversity in this region are almost entirely unknown.

Mellish Rise/Kenn Plateau

The Mellish Rise and Kenn Plateau, at the northern end of the Lord Howe Rise, are almost unknown geologically. Swath-mapping of the region will provide geological framework information which has direct relevance to any assessment of the hydrocarbon potential of the northern Lord Howe Rise and northeast Australia.

Exmouth/Scott Plateau margins

Swath-mapping of the margins of the Exmouth and Scott Plateaus, adjacent to the North West Shelf, Australia's premier hydrocarbon province, will provide new framework information that will lead to an improved understanding of the region.

The Marine Science and Technology Plan recognised that a program to systematically map the shape and form of the seabed in the AMJ would necessarily be a long-term effort. Based on a sea-going effort of 100 days per annum and an average coverage rate of 6000–7000 km^2 per day, it is estimated that it would take 15 years to map all off-shelf areas of the AMJ. To this would be added the extra time needed to carry out the seabed sampling required to ground truth these data; this is estimated at a further 30 days per annum. However, systematic mapping of the geomorphic shelf is a much slower process, by virtue of the smaller swath width and average daily coverage of 200–300 km^2. A single system operating for 300 days per annum would take at least 30 years to complete coverage of this region. As it is unlikely that multiple vessels are likely to be deployed on this task, it is probable that the morphologic shelf will be surveyed on a priority basis, concentrating initially on the highest use or most environmentally vulnerable areas.

CONCLUSIONS

While ownership of offshore resources provided under the United Nations Convention on the Law of the Sea bestows certain rights (including the right to exploit resources), it also carries a range of obligations. There is a key national need for Australia to acquire certain basic data sets that can then be made available to all organisations and inviduals working in the marine environment in order to meet these obligations. These needs have been laid out in the Commonwealth's Oceans Policy and in the companion Marine Science and Technology Plan.

The most critical of the baseline data sets is the detailed depth and form of the seafloor, and the nature of the shallow substrate, particularly in high-use areas. Such information underpins the activities of virtually all government, industry and academic sectors working offshore. Knowledge of the seabed is also critical to the issues of multiple sequential land use throughout the Australian Marine Jurisdication. The current state of such knowledge is extremely variable, with adequate information only being available for about 5% of Australia's offshore. However, with the release of the Oceans Policy, there is now an acknowledgement in the Australian marine community that systematic and prioritised collection of seabed data is in the national interest.

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(accepted 13 October 1999)

SOUTHERN OCEAN CURRENTS AND CLIMATE

by S. R. Rintoul

(with six text-figures; figures 2 and 6 in colour)

RINTOUL, S.R., 2000 (31:v): Southern Ocean currents and climate. *In* Banks, M.R. & Brown, M.J. (Eds): *TASMANIA AND THE SOUTHERN OCEAN. Pap. Proc. R. Soc. Tasm.* 133(3): 41–50. ISSN 0080–4703. CSIRO Marine Research and Antarctic Cooperative Research Centre, GPO Box 1538, Hobart, Tasmania, Australia 7001.

The Antarctic Circumpolar Current (ACC) carries about 130 to 150 x 10^6 m^3 s^{-1} along a 20 000 km path circling Antarctica, making it the largest current in the world ocean. The flow of the ACC connects the ocean basins, allowing water, heat, and other properties to be carried from one basin to another. The interbasin connection provided by the ACC is a key link in a global ocean circulation, sometimes called the "great ocean conveyor", which strongly influences the climate of the Earth on time-scales of years to centuries.

Unlike most other regions of the ocean, fluctuations of the currents play a central role in the heat and momentum budget of the Southern Ocean. The fluctuations carry momentum, supplied by the strong winds, down to where pressure forces against seafloor topography can compensate the wind forcing, and also carry heat poleward to balance the heat lost by the ocean to the cold atmosphere south of the ACC.

While the circumpolar current is the dominant circulation feature of the Southern Ocean, there are important flows in the north–south and vertical planes. Deep water shoals as it spreads south across the Southern Ocean, ultimately reaching the sea surface near Antarctica. Strong interactions with the atmosphere and sea-ice modify the upwelled water where it reaches the surface: some water is made lighter by warming and freshening due to rainfall and sea-ice melt, while some is made more dense by cooling and addition of salt rejected during freezing of sea-ice. The water mass transformations driven by air–sea exchange in the Southern Ocean allow deep water to be converted to lighter intermediate water, as required to complete the loop of the global conveyor.

Key Words: Southern Ocean, climate, Antarctic Circumpolar Current, overturning circulation, temporal variability, water mass formation, eddy heat flux.

INTRODUCTION

While Douglas Mawson and his men endured consecutive winters at Commonwealth Bay on the Antarctic coast, the "Home of the Blizzard" (Mawson 1930), the members of the expedition who had returned to Hobart were fighting their own battles against the elements. Edgar Waite, zoologist on the 1911–14 expedition, described their attempts to gather some of the first winter oceanographic observations in the Subantarctic Zone (Mawson 1940):

> We had hoped against hope for weather fine enough to enable the trawl to be put over, but not a single day sufficiently favoured us; in fact, the whole tale of the cruise may be expressed as gales of wind, big seas, rain, snow and general gloom. On days when the seas were somewhat less tumultuous, sounding was essayed, but only three successful records were made. Considerable property was lost ... and 2,000 feet of sounding wire went to the bottom in an unorthodox manner.

Gathering oceanographic data from the Southern Ocean remains a challenging endeavour; log books of recent Southern Ocean expeditions contain their share of tales of "gloom" and "unorthodox" deployments of equipment.

The reputation of the Southern Ocean is built on experiences such as Waite's: mariners venture south with the expectation of encountering the strongest winds and largest waves to be found in the world ocean, but the Southern Ocean is also unique in the degree to which its currents affect both regional and global climate. It occupies the only band of latitudes where ocean waters circle the globe. This simple geographical fact turns out to have profound implications for the currents of the Southern Ocean and for their influence on the Earth's climate. Within this circumpolar channel lies the world's largest current, the Antarctic Circumpolar Current (ACC), which flows from west to east around the Antarctic continent, connecting the ocean basins to form a network of ocean currents known as the global overturning circulation, or "ocean conveyor". By transporting heat from one region to another, this global circulation is a vital cog in the heat engine which controls the Earth's climate. The link provided by the ACC allows anomalies formed in one basin to propagate to distant basins, where they affect regional and global climate (e.g. White & Peterson 1996, Mikolawejicz & Maier-Reimer 1990). (For a more complete overview of the influence of the ocean on global and Australian climate, see Piexoto & Oort 1992, Rintoul *et al.* 1996 and Godfrey & Rintoul 1998.)

Interactions between the ocean, atmosphere and sea-ice modify surface waters and cause them to sink and spread into the interior of the ocean. Southern Ocean water masses formed in this way renew a substantial fraction of the world ocean volume. Changes in the formation rate or properties of these water masses will change the rate at which the ocean stores heat, freshwater and gases such as carbon dioxide, thus influencing climate.

Southern Ocean currents also play an important role in the carbon cycle. Somewhat less than half of the carbon dioxide released to the atmosphere by human activities (primarily burning of fossil fuels and land clearing) remains in the atmosphere. The rest is taken up by the ocean or by land plants and soils, but the relative contributions of ocean and land are not well known. The Southern Ocean as a whole acts as a significant net "sink" of atmospheric carbon dioxide, although the exchange between the atmosphere and this ocean varies dramatically with location and season. The physical and biogeochemical processes

which control this exchange are themselves controlled to a large degree by ocean currents. While the Southern Ocean contribution to the oceanic carbon cycle is an important part of the climate story, this issue will not be addressed here. Interested readers are referred to Sundquist (1993), Heimann (1993) and, for an Australian perspective, to Rintoul *et al.* (2000).

This paper reviews recent progress in understanding the link between Southern Ocean currents and climate, with an emphasis on work carried out in the Australian sector. Australia, and Tasmania in particular, has had a long historical connection to exploration and scientific expeditions to the Southern Ocean and Antarctica. For example, when Cook lowered anchor in what is now Adventure Bay on Bruny Island, he had already made several important observations of Southern Ocean currents, including the presence of a strong current setting his ship to the east between 40°S and 60°S, and the surprising fact that water temperatures near Antarctica *increased* with depth near 100 fathoms (200 m), in contrast to all lower latitude oceans. This unusual temperature structure reflects the circulation of a "global ocean conveyor", as described in the final section of the paper.

THE ANTARCTIC CIRCUMPOLAR CURRENT

A broad-brush view of the mean global ocean circulation is shown in figure 1. The property plotted is "dynamic height", which serves as a streamfunction for ocean currents, much as pressure contours do for an atmospheric weather map: where the contour lines are close together, the currents are strong; where they are far apart, the currents are weak. Figure 1 illustrates the strength and circumpolar connection of the ACC. (Note that some important features of the ocean circulation such as intense boundary currents along the western side of the mid-latitude ocean basins are not well represented in the smoothed mean field shown here.)

Despite the importance of the ACC to the climate system, there have been few measurements of the current. Much of what we know about the ACC is derived from experiments conducted in Drake Passage in the late 1970s. These observations showed that the ACC consisted of a number of deep-reaching fronts or current jets which carried about 134×10^6 $m^3 sec^{-1}$ to the east (Nowlin & Klinck 1986). More recently, hydrographic sections at other longitudes have confirmed the circumpolar extent of the fronts observed in Drake Passage (e.g. Orsi *et al.* 1995). Satellite measurements of sea surface temperature (e.g. Hughes *et al.* 1998; and fig. 2 opposite) and sea surface height (e.g Gille 1994) have revealed further details of the rich structure of the ACC fronts. The velocity measurements in Drake Passage also showed that fluctuations in the ACC, or "eddies", were important to the dynamical and thermodynamical balance of the ACC, as described in more detail below.

Because Drake Passage is the narrowest constriction through which the current must pass, and so may not be representative of the current as a whole, measurements were extended to other parts of the Southern Ocean during the World Ocean Circulation Experiment (WOCE). In particular, the most intensive measurements of the ACC made during WOCE were carried out south of Tasmania. These studies included ship-based observations, moored time series measurements, satellite remote sensing, and numerical experiments.

The centrepiece of the Australian studies of the ACC has been a hydrographic transect between Tasmania and Antarctica along roughly 140°E (WOCE line SR3), which has been occupied six times between 1991 and 1996 (Rintoul & Bullister 1999, Rosenberg *et al.* 1995a, b, 1996). Upper ocean temperatures have been monitored along a nearby line from 1993 to the present as part of a joint Australia–France–USA program known as SURVOSTRAL (Rintoul *et al.* 1997). To orient the reader for the following discussion, a description of the major circulation features and water masses found on the SR3 transect is given here.

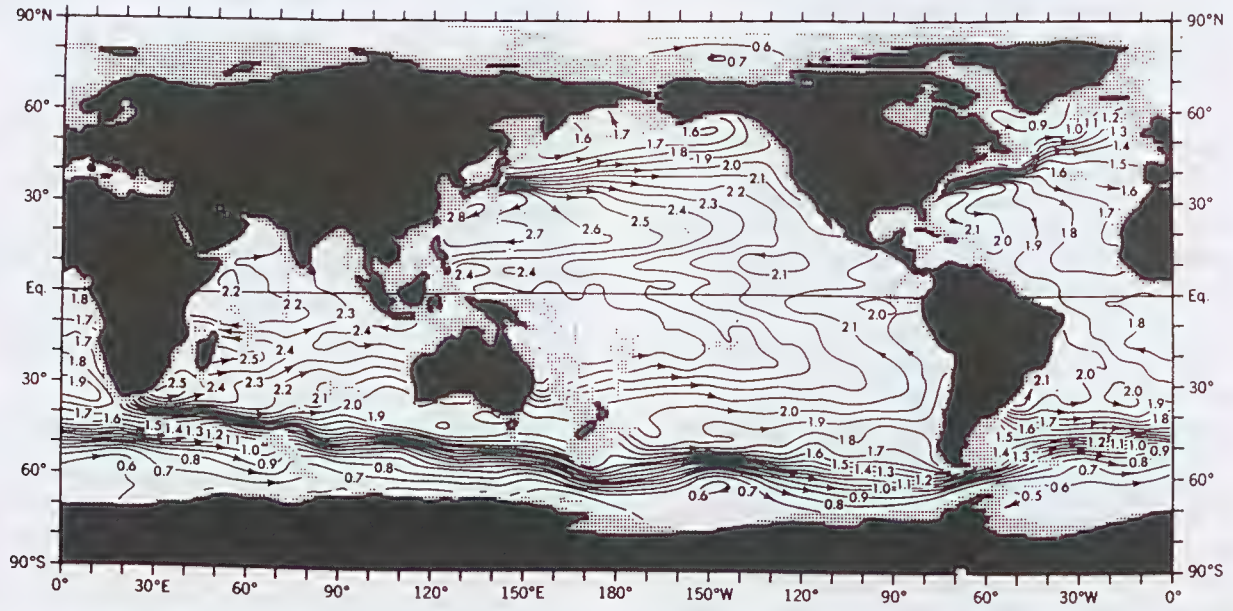

FIG. 1 — Annual mean dynamic height (anomaly of geopotential thickness, 10 $m^2 s^{-2}$) at the sea surface relative to 2000 m (from Levitus & Boyer 1994). The arrows indicate the inferred direction of flow; the speed of the flow is inversely proportional to the spacing between the contours.

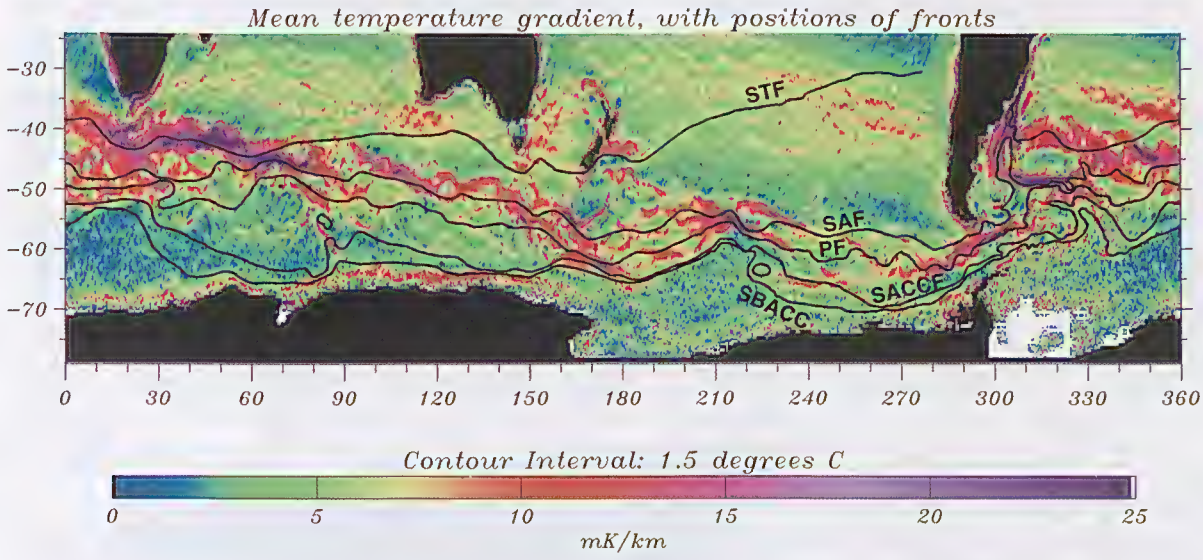

FIG. 2 — Magnitude of the mean sea surface temperature gradient, from 44 months of observations by the Along-Track Scanning Radiometer on the ERS-1 satellite (Hughes et al. *1998). Superposed are positions of (from north to south) the Subtropical Front (STF), Subantarctic Front (SAF), Polar Front (PF), Southern ACC Front (SACCF), and southern boundary of the ACC (SBACC), from Orsi* et al. *(1995).*

Potential temperature along the transect, as measured in January 1995, is shown in figure 3A. The temperature of the water column generally decreases from north to south, reflected in the shoaling of isotherms to the south. The slope of the isotherms is particularly steep at a number of fronts, which are labelled at the top of figure 3A. These fronts circle the globe and separate zones where the water properties are more or less uniform. (For a discussion of the criteria used to identify the individual fronts, see Orsi *et al.* 1995 and Rintoul & Bullister 1999.) The fronts correspond to jets of strong flow, which effect most of the transport by the ACC. The fronts evolve in time and are not stationary features: the section illustrated in figure 3A, for example, cuts across a meandering loop of the Subantarctic Front.

Figure 3A is representative of summer conditions, when the surface layer has been warmed by the atmosphere. Below the warm summer mixed layer (pressures > 100 dbar [1 dbar is approximately equal to 1 m in depth]), remnants of the deeper winter mixed layers can be seen. The thick layer of uniform temperature (8–9°C) between the Subtropical Front (at 46°S) and the Subantarctic Front (at 51°S) is produced by deep (> 500 dbar) convection in winter. The water mass produced by this deep winter mixing is known as Subantarctic Mode Water (see below). A temperature minimum layer is found south of 53°S. This cold layer is also formed by convection driven by strong winter cooling. The warmer summer mixed layers are not as deep, and so a remnant layer of "winter water" is left, forming a temperature minimum between 100 and 250 dbar.

Salinity from the same transect is shown in figure 3B. The Subtropical Front separates saline subtropical water (salinity > 34.8 psu) from fresher subantarctic waters. Between the Subtropical and Subantarctic Fronts, the salinity minimum of the Antarctic Intermediate Water is found between 1000 and 1500 dbar. A salinity maximum, underlying the intermediate water, marks the Lower Circumpolar Deep Water layer. The high salinity water originates in the northern Atlantic and spreads south, ultimately merging with the eastward flow of the ACC. At the southern end of the section, the thin layer of fresh, cold water found over the Antarctic continental slope is Antarctic Bottom Water.

As for salinity, the oxygen distribution along the transect shows a number of extrema which correspond to particular water masses (fig. 3C). The Subantarctic Mode Water forms a thick layer of high oxygen, as a result of exchange with the atmosphere during active convection in winter. The Antarctic Intermediate Water is also relatively high in oxygen but not as rich as the overlying mode water. An oxygen minimum layer indicates deep water which has been isolated from the sea surface for a long time. It is formed during long transits of the Indian and Pacific Oceans, and is known as Upper Circumpolar Deep Water once it returns to the Southern Ocean. The Antarctic Bottom Water is high in oxygen, reflecting the fact that this water has recently sunk from the sea surface.

Measurements of temperature and salinity (from which density can be calculated) can be used to determine the velocity at one depth relative to any other depth. If the velocity relative to the seafloor is integrated along the section, the mean net transport across the section is 143 x 10^6 m^3 sec^{-1} to the east, with a range from 131 to 158 x 10^6 m^3 sec^{-1} (fig. 4). The amount of water entering the Pacific basin south of Australia is about 10 x 10^6 m^3 sec^{-1} larger than that leaving the Pacific through Drake Passage. This extra eastward flow south of Australia is required to compensate the outflow from the Pacific to the Indian Ocean via the Indonesian passages. (Note that these estimates do not include the so-called "barotropic" part of the flow, which cannot be easily measured using ship-based instrumentation.)

Careful analysis of water property distributions indicates the origin of each of the current branches which cross SR3. By combining this information with recent transects to the

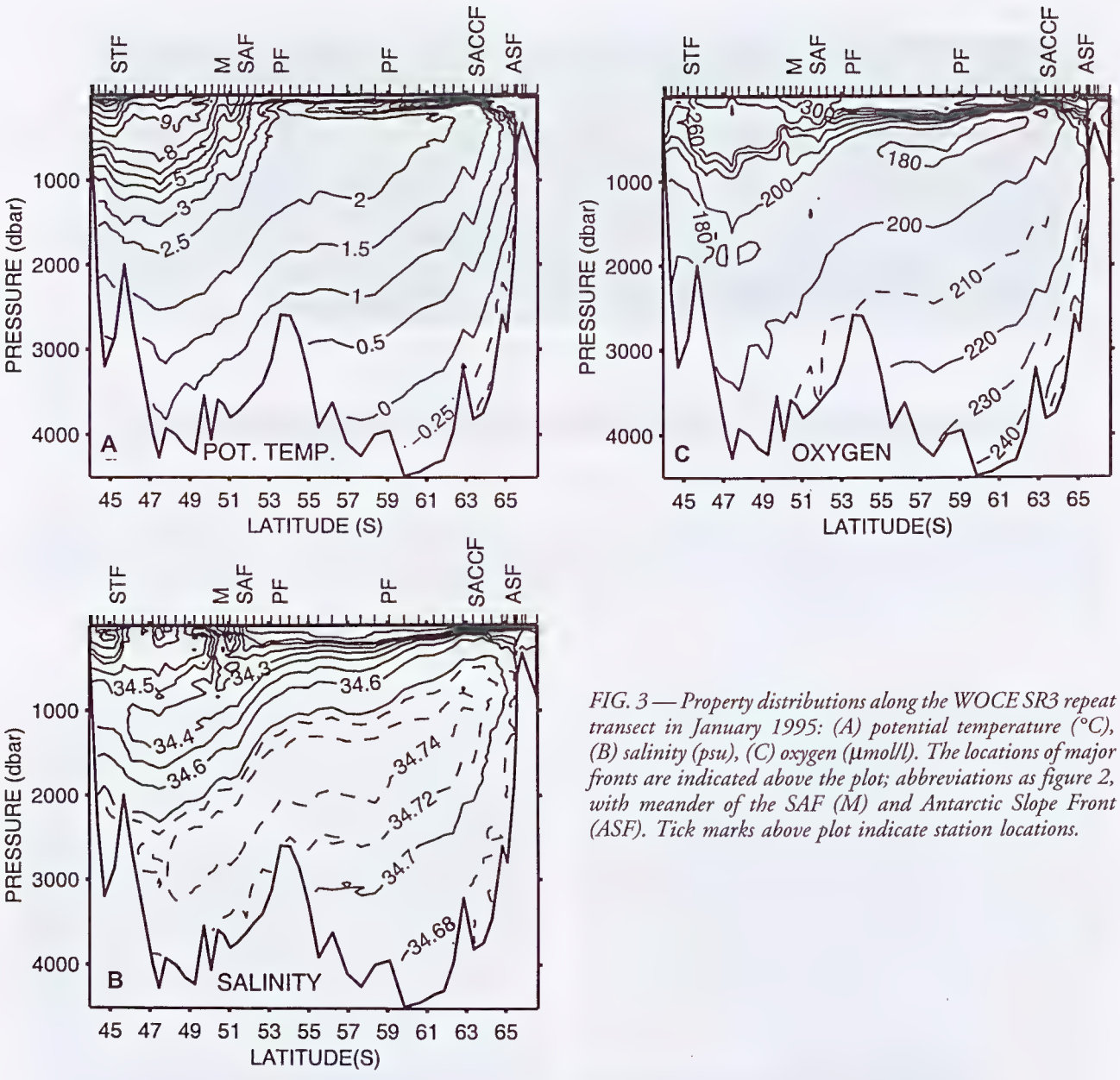

FIG. 3 — Property distributions along the WOCE SR3 repeat transect in January 1995: (A) potential temperature (°C), (B) salinity (psu), (C) oxygen (µmol/l). The locations of major fronts are indicated above the plot; abbreviations as figure 2, with meander of the SAF (M) and Antarctic Slope Front (ASF). Tick marks above plot indicate station locations.

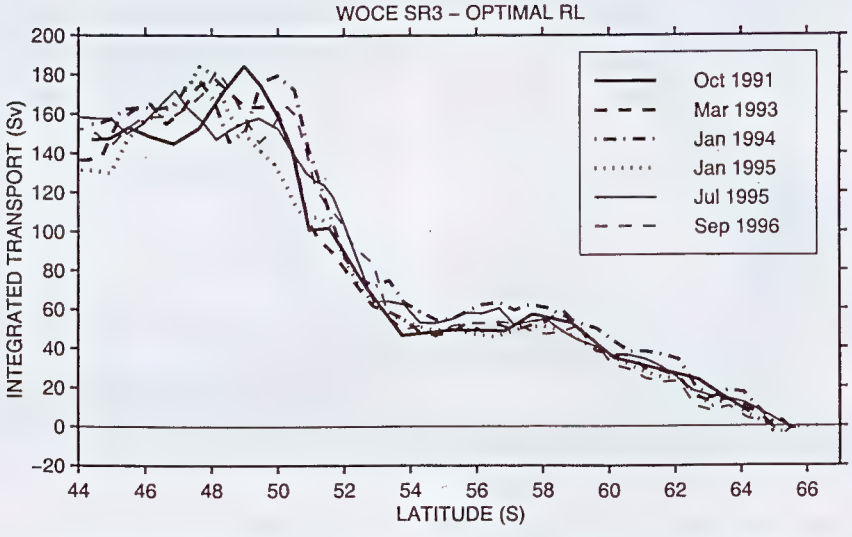

FIG. 4 — Transport integrated from south to north for six occupations of the WOCE SR3 section, in units of 10^6 m^3 s^{-1}. Positive values are toward the east.

east and west of SR3, and with climatological averages of historical data, a sketch of the major currents south of Tasmania can be constructed (fig. 5). (The current paths in figure 5 rely in particular on WOCE sections P11S [Sokolov & Rintoul 2000] and P11A along 155°E, the Olbers *et al.* [1992] atlas, and the SR3 repeat transects. The inferred flow paths are also consistent with the trajectories of neutrally buoyant floats at 900 m depth [Davis 1999]. See Rintoul & Sokolov [2000] for more details.) The mean transport (±1 standard deviation) of each of the currents crossing SR3 is indicated in figure 5.

Some, but not all sections, show a strong westward flow immediately south of Tasmania. The temperature and salinity of this water indicates an origin in the Tasman Sea. Sokolov & Rintoul (2000) showed that water enters the Tasman Sea from the south, mixes with subtropical water, and returns to the south adjacent to the coast of Tasmania. The transport of this branch (TAS, fig. 5) is $8 \pm 13\ 10^6\ m^3\ s^{-1}$ to the west, the large standard deviation reflecting the highly variable nature of this flow. Further south, a deep-reaching, anti-clockwise gyre (SAZ) carries about $22 \pm 8\ 10^6\ m^3\ s^{-1}$. The low salinity and high oxygen of the intermediate water

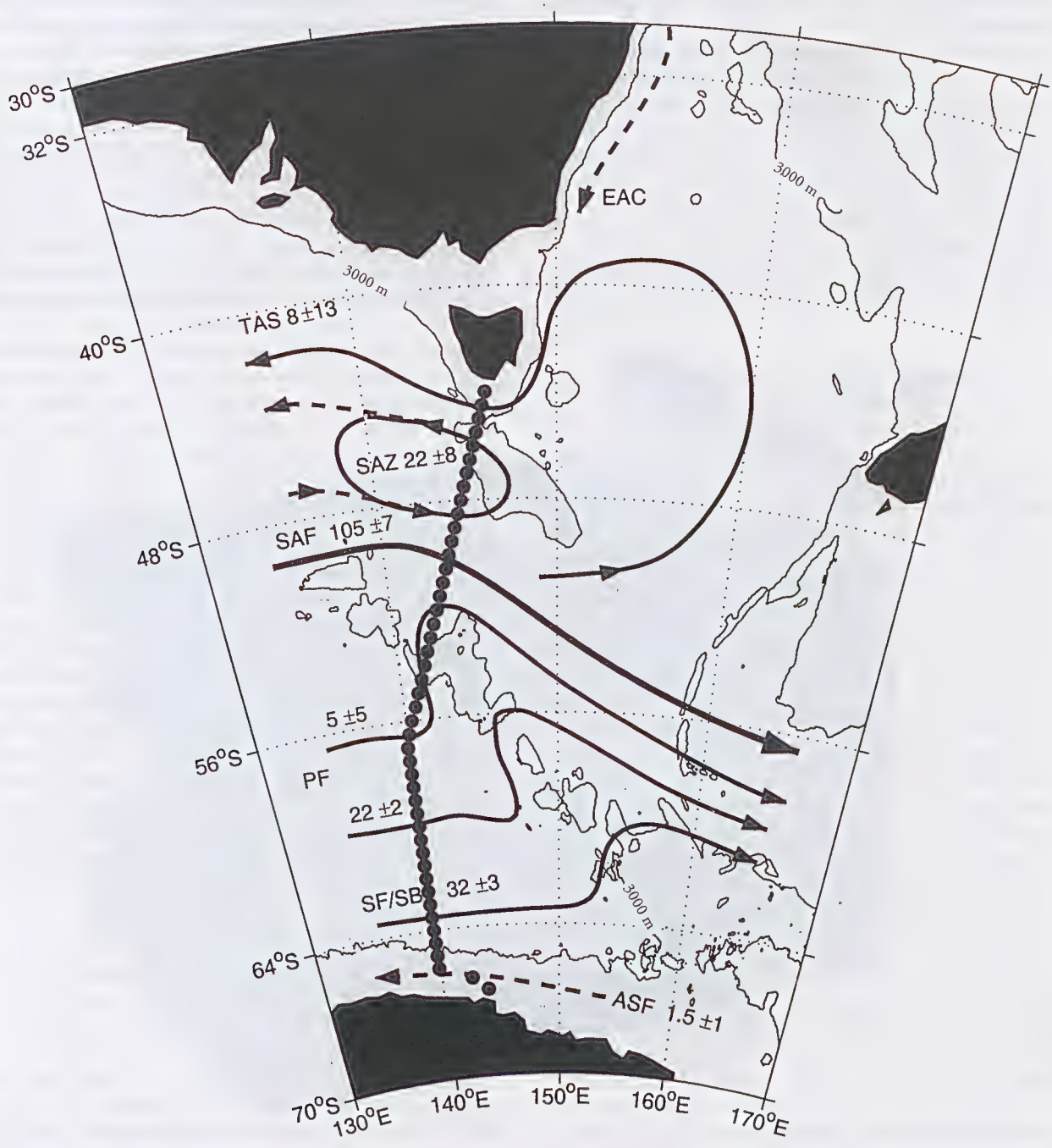

FIG. 5 — A schematic view of the main currents south of Tasmania (see text for a description of the data on which the figure is based). The numbers give the mean (± 1 standard deviation) transport of each current branch, based on the six repeats of SR3. 3000 m isobath is shown.

in this gyre confirms that this is a local recirculation of southern-origin (i.e. not subtropical) water. The strongest current jet crossing SR3 is the Subantarctic Front, with a transport of 105 ± 7 10^6 m^3 s^{-1}. East of SR3, the front turns to the southeast, roughly parallel to the Southeast Indian Ridge. The Polar Front consists of two branches on each of the SR3 sections. The northern branch has a mean transport of 5 ± 5 10^6 m^3 s^{-1}, while the southern branch carries 22 ± 2 10^6 m^3 s^{-1}. Between the two expressions of the Polar Front the flow is weakly toward the west. Summing the transport in the two branches of the Polar Front and the westward flow between them gives a transport of 31 (± 6) 10^6 m^3 s^{-1}. Both fronts turn north when they encounter the shallower water over the ridge (as required to conserve potential vorticity), cross the ridge, and turn back to the southeast.

In figure 5, the two southernmost fronts associated with the ACC (the southern ACC front and the southern boundary of the ACC — Orsi *et al.* 1995) have been added together (SF/SB). The transport of the combined fronts is 32 ± 3 10^6 m^3 s^{-1} to the east. The small standard deviations reflect the steadiness of the southern fronts of the ACC.

The repeats of SR3 provide the first detailed look at the variability of the ACC south of Australia, from the sea surface to the seafloor. Variability of upper ocean thermal structure in this region has also been described by Rintoul *et al.* (1997).

DYNAMICS OF THE ANTARCTIC CIRCUMPOLAR CURRENT AND THE ROLE OF EDDIES

The fact that the ocean is not blocked by land in the latitude band of Drake Passage has additional dynamical implications for the currents of the Southern Ocean. The fundamental balance of forces governing most open ocean flows is a balance between the Coriolis force and the pressure gradient force. To have net north–south flow in an ocean basin requires pressure differences in the east–west direction. In most ocean basins, land boundaries surrounding the ocean exist to support the required pressure gradients. In the circumpolar channel of the Southern Ocean, there can be no net pressure gradient in the east–west direction and, hence, no net north–south flow (except in thin frictional layers, or below the depth of bathymetric features like ocean ridges, which can support the required pressure gradients). The dynamics of the ACC differ from most other ocean currents and are still not completely understood. (See e.g. Warren *et al.* 1996, Hughes 1997, Olbers 1998, Warren *et al.* 1998 for a commentary on the on-going debate over ACC dynamics.)

One way in which the ACC differs from its lower-latitude counterparts is in the central role that fluctuations in the current play in the dynamical and thermodynamical balance. Deviations from the east–west average current, frequently called "eddies", transfer the force of the wind blowing on the sea surface downward to the deep ocean. The momentum carried to the deep sea drives deep ocean currents, which establish pressure forces against the seafloor ridges to balance the momentum supplied by the wind (Munk & Palmèn 1951). In other words, the driving force of the wind is compensated by a force exerted by the deep flow on seafloor topography; the deviations from a steady, strictly east–west flow act to transfer the momentum vertically through the water column. (Both variations in time and large-scale variations in space due to north–south shifts of the ACC axis contribute to the "eddy" fluxes.)

The eddies are important to the heat balance of the Southern Ocean, as well as the momentum balance. The ocean loses heat to the atmosphere south of the ACC but, due to the absence of land boundaries to support pressure gradients, there can be no poleward mean flow of warm water in the upper ocean to provide this heat (as e.g. the Gulf Stream does in the Atlantic). The poleward heat transport required to balance the heat lost to the atmosphere is instead carried by the eddy heat flux which results from correlations between velocity and temperature fluctuations. It turns out that eddies which carry heat poleward simultaneously carry momentum downward, so that the heat and momentum balances of the Southern Ocean are linked (Johnson & Bryden 1989, Wolff *et al.* 1991).

Recently Australian scientists have deployed current meter moorings in the ACC to directly measure the eddy fluxes for the first time in this region. The current meter measurements confirm that the eddy heat flux is poleward, and that the eddies carry momentum downward through the water column, as required for the dynamical balance described above to hold (Phillips & Rintoul 2000). Satellite measurements of sea surface height variability show clearly that eddy energy is enhanced along the entire path of the ACC, and particularly so where the current interacts with sea floor bathymetry (e.g. Morrow *et al.* 1994).

Because of computer limitations, the present generation of climate models cannot explicitly resolve the small-scale eddies that play such a significant role in the dynamics and thermodynamics of the Southern Ocean. Instead, these eddies need to be parameterised in some way. New parameterisations of their effect on property transports dramatically improve the simulation of a number of features of the Southern Ocean: the temperature and salinity of the deep ocean, the depth of the mixed layer, and the depth to which chemical tracers entering from the atmosphere penetrate into the ocean (Gent & McWilliams 1990, McDougall *et al.* 1996, Hirst & McDougall 1996, England & Hirst, 1997). These improvements result in part because the parameterisation represents the dynamical instabilities of ocean currents more realistically, and in part because artificially large diffusivities are no longer required to keep the model stable (Hirst & McDougall 1998). Correctly simulating these aspects of the ocean circulation is crucial if the model is to properly represent the processes by which the ocean absorbs, stores and transports heat and carbon dioxide. Models incorporating this parameterisation are therefore likely to provide more reliable predictions of climate change.

THE GLOBAL OVERTURNING CIRCULATION AND WATER MASS FORMATION

The strong eastward flow of the ACC carries water, heat and other properties between each of the Southern Hemisphere basins. In fact, the interbasin exchange provided by the ACC is at least an order of magnitude larger than all other interbasin flows combined. As a result, the ACC is an important link in the global pattern of ocean currents known as the "overturning circulation" (or "ocean conveyor").

To a large extent, the properties of a given volume of sea water are determined when the water is in communication with the atmosphere at the sea surface, and these characteristic properties (e.g. temperature, salinity, oxygen concentration) are carried with the water parcel when it sinks into the interior of the ocean. Away from the sea surface, the properties of sea water are only slowly modified by mixing with surrounding waters. The water characteristics observed in the interior of the ocean, therefore, reflect the properties where the water left the sea surface.

Most of the water in the ocean is cold (75% of the ocean volume is cooler than 4°C – Worthington 1981) and, therefore, must have left the sea surface at high latitude, where cold surface temperatures are found. The sinking of cold, dense water at high latitudes of the North Atlantic and Southern Hemisphere is balanced by a return flow of warmer, lighter water to resupply the sinking regions. The flow of light water toward these regions, balanced by cold, dense water flowing away from them, forms the global overturning circulation. To close the loop, upwelling of deep water must occur somewhere to resupply the warm upper limb of the overturning circulation. Because the temperature difference between the deep and upper ocean limbs can be large, the overturning circulation can transport heat very efficiently and, hence, is an important part of the climate system. The sinking of dense surface water which has been in contact with the atmosphere also carries oxygen to the deep ocean: without sinking of deep and bottom water, there would be no oxygen in the deep sea.

The Southern Ocean plays several key roles in the overturning circulation. First, by connecting the ocean basins, the ACC allows such a global circulation pattern to exist. Second, the ACC transports deep water formed in the sinking regions to remote parts of the ocean. Third, the Southern Ocean is now believed to be the primary place where deep water is converted back to lighter water, as required to complete the loop.

The characteristic properties of about 50% of the world ocean volume are set through air–sea interaction in the Southern Ocean. These water masses are produced by an overturning circulation in the north–south plane (fig. 6). Relatively saline deep water, which originates in the North Atlantic, spreads to the south and shoals while being carried to the east by the strong flow of the ACC. (The presence of this relatively warm and salty water beneath the cool, fresh water in direct contact with the high-latitude atmosphere is responsible for the unexpected temperature inversion first noted by Captain Cook, as described in the Introduction.) Winds acting on the sea surface drive a divergence of surface waters which is balanced by upwelling of deep water. Some of the upwelled water is converted to denser bottom water (by cooling, mixing with cold but fresh water over the shelf, and the addition of salt released during freezing of sea-ice), while the remainder is converted

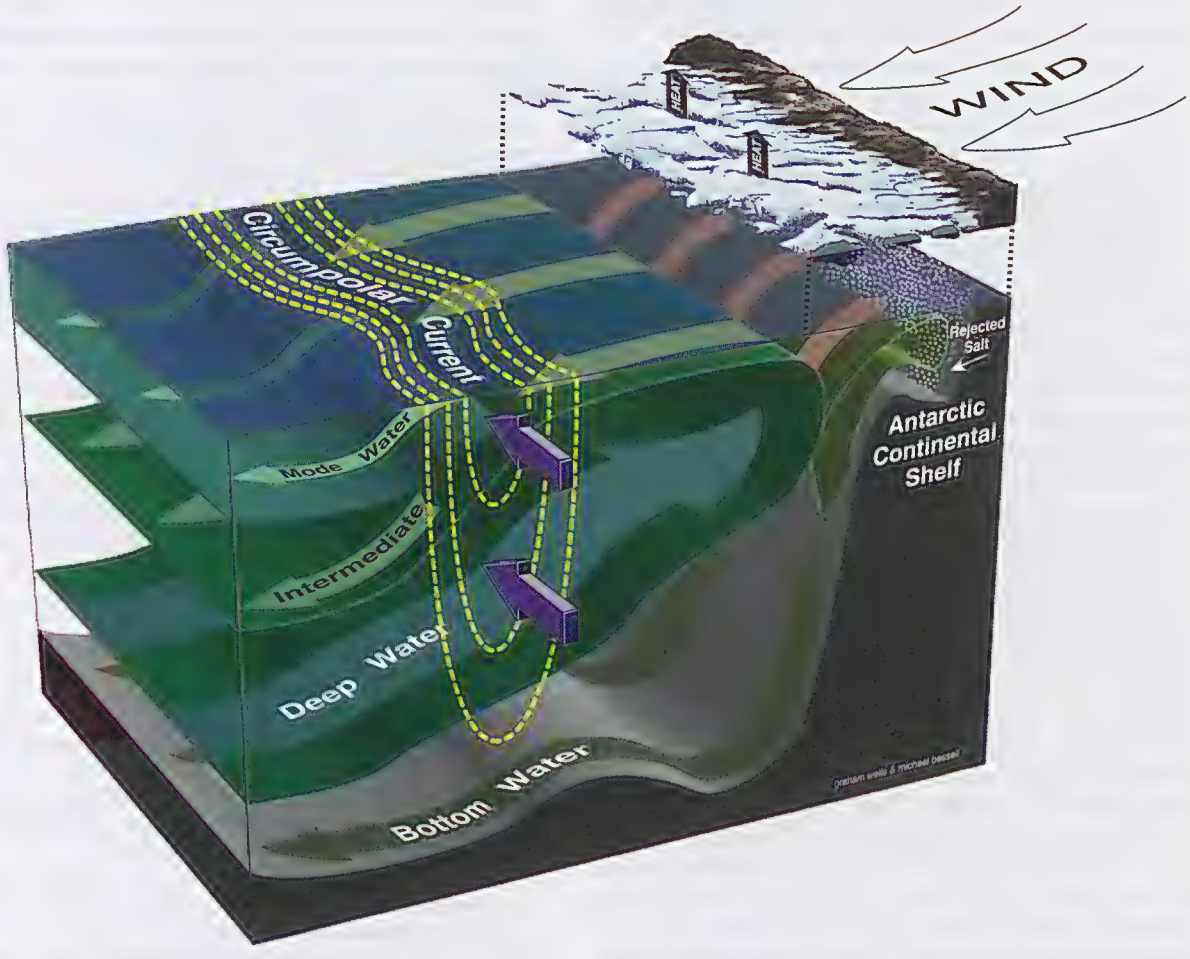

FIG. 6 — A schematic view of the overturning circulation in the north–south plane in the Southern Ocean. Deep water upwells near Antarctica as a result of divergent wind-driven currents near the surface. Part of the upwelled deep water is driven north and converted to lighter intermediate and mode water by warming and freshening at the sea surface. The remainder is converted to denser Antarctic Bottom Water by cooling and addition of salt rejected during sea-ice formation.

to less dense waters (by warming, and by freshening through precipitation and ice melt). Once formed, the Southern Ocean water masses spread to lower latitudes, where their relatively high oxygen concentrations "renew" the intermediate and abyssal waters of the world ocean.

This picture of the circulation in the meridional plane is largely unchanged from that first proposed by Sverdrup in the 1930s (Sverdrup 1933). Only recently have we been able to fill in some of the details, including where the deep and bottom water is formed, where it is converted to less dense water, and how the water masses participating in this loop may change with time.

With regard to sinking of dense water near Antarctica, we have found that the Antarctic coastline between 140°E and 150°E appears to be a much more significant source of bottom water than previously appreciated. A re-analysis of historical data suggests that up to 25% of the global inventory of Antarctic Bottom Water may be formed in this sector of the Antarctic coastline (Rintoul 1998); previous estimates had suggested 0.5% or less of the total is formed there (e.g. Carmack 1977). Bottom water formed in this region is high in dissolved gases such as oxygen and CFCs, and so is an important means of "ventilating" the deep ocean (Rintoul & Bullister 1999). In particular, the water which fills the abyssal layers of the eastern Indian and Pacific Oceans is cold, fresh and high in oxygen, because of the influence of the bottom water formed between 140°E and 150°E. (See Bindoff *et al.* [2000] for a more complete discussion of Antarctic Bottom Water formation.)

Some recent models suggest that most of the conversion of North Atlantic Deep Water to lighter intermediate water occurs in the Southern Ocean (e.g. Döös & Coward,1997), rather than by upwelling distributed uniformly throughout the remainder of the world ocean, as traditionally assumed (e.g. Stommel & Arons 1960). Upwelling of deep water at high latitude followed by warming and freshening at the sea surface forms Subantarctic Mode Water (SAMW) and Antarctic Intermediate Water (AAIW). Both of these water masses are renewed on decadal time-scales and can change relatively quickly in response to changes in the atmosphere. Recent work by Australian investigators has focused on these water masses in an attempt to document whether the interior of the ocean shows evidence of climate changes in recent decades.

Comparisons of recent data collected in the Tasman Sea, Indian and Southern Oceans with historical data collected mainly in the 1950s & 1960s show that SAMW originating in the Southern Ocean has warmed in both the Indian Ocean and Tasman Sea, with maximum temperature increases of 0.5°C at 300 m (Bindoff & Church 1992, Salinger *et al.* 1996). This significant warming is consistent with broad-scale warming of the surface waters where SAMW is formed (Bindoff & McDougall 1994). Similar changes have now been observed throughout the Pacific Ocean (Wong *et al.* 1999). These analyses also show that AAIW near 1000 m depth has freshened, implying that the surface waters feeding the AAIW are now fresher than in the early 1960s. This freshening could be caused by an increase in rainfall between 50°S and 70°S fed by increased evaporation at low latitudes. The warming and freshening of the surface layers required to explain the observed temperature and salinity changes is consistent with the response of climate models to increasing concentrations of greenhouse gases (Bindoff & McDougall 1994).

SUMMARY

Southern Ocean currents have a profound impact on the global ocean circulation, and hence the Earth's climate. The massive eastward flow of the ACC carries water, heat, salt and other properties between the ocean basins. Anomalies transported by the ACC can therefore influence the climate of regions remote from the location where the anomaly was created. Repeat transects between Tasmania and Antarctica have defined the transport of the main current branches south of Australia, and their variability, for the first time.

The dynamics of the ACC remain a topic of active debate. Direct current measurements south of Tasmania have quantified the rate at which fluctuations of the ACC, or "eddies", transport momentum downward and heat poleward, as anticipated from theory but not previously observed in the Australian sector. Recent advances in representing the effects of small-scale eddies on the large-scale circulation have led to dramatic improvements in the ability of ocean models to simulate key features of the Southern Ocean.

The overturning circulation in the north–south plane, and the associated water mass transformations driven by air-sea fluxes, also play an important part in the climate system. Deep water formed in the North Atlantic spreads south and upward across the Southern Ocean, ultimately reaching the sea surface near Antarctica. The upwelled deep water is converted to both lighter and denser water masses which flow north to renew the intermediate and abyssal layers of the world ocean. In this way the Southern Ocean is a key link in the global overturning circulation which strongly influences the evolution of the climate system on time-scales of years to millennia.

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I thank John Church, Nathan Bindoff and Mark Rosenberg for their valuable contributions to the organisation, fieldwork, and interpretation of the research summarised here. This work was supported by Environment Australia's Climate Change Research Program and the Antarctic Cooperative Research Centre. Assistance from the Australian National Antarctic Research Expeditions and the officers and crew of the RSV *Aurora Australis* is also gratefully acknowledged. This paper is a contribution to the World Ocean Circulation Experiment.

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BOTTOM WATER FORMATION AND POLYNYAS IN ADÉLIE LAND, ANTARCTICA

by Nathaniel L. Bindoff, Stephen R. Rintoul and Robert Massom

(with five text-figures)

BINDOFF, N.L., RINTOUL, S.R. & MASSOM, R., 2000 (31:v): Bottom water formation and polynyas in Adélie Land, Antarctica. *In* Banks, M.R. & Brown, M.J. (Eds): *TASMANIA AND THE SOUTHERN OCEAN. Pap. Proc. R. Soc. Tasm.* 133(3): 51–56. ISSN 0080–4703. Antarctic CRC, GPO Box 252-80, Hobart, Tasmania, Australia 7001 (NLB, SRR, RM); and CSIRO Division of Marine Research, GPO Box 1538, Hobart, Tasmania, Australia 7001 (SRR).

Antarctic Bottom Water is the coldest and densest water found in the global ocean. It spreads into all the major ocean basins, carrying the cold water towards the equatorial regions, and is a central component of the global thermo-haline circulation. However, the mechanisms of bottom water formation are not well established; its geographical distribution and rate of formation have yet to be fully quantified.

Polynyas, which are large persistent openings in sea-ice that form during the winter near the Antarctic Coast, play a central role in the formation of Antarctic Bottom Water.

This paper describes the bottom water formation around the Antarctic continental margin with particular emphasis on the processes and mechanisms of the Adélie Land Bottom Water formation near Dumont D'Urville south of Tasmania.

Key Words: Antarctic Bottom Water, polynya, brine rejection, Adelie Land Bottom Water.

INTRODUCTION

Antarctic Bottom Water (AABW) is one of the most important water-masses in the global ocean. It is the coldest, densest water found in the deep ocean. This water is found in all of the deep basins around the Antarctic continent, broken only by the relatively shallow sill through Drake Passage. Estimates of the volume of AABW (defined by water denser than neutral density — Jackett & McDougall 1997 [$\gamma^n > 28.27$ kg.m^{-3}]) show it to occupy 3.5% of the volume of the ocean (Orsi *et al.* 1999) and affect, through mixing and advection, more than 41% of the global oceanic volume (Worthington 1981). Estimates of the production rate of bottom water vary but range from 8–12 Sv (Orsi *et al.* 1999 [1 Sv=10^6 m^3.s^{-1}]), giving a renewal time (defined here as the volume occupied by AABW divided by production rate) of 180–120 years, respectively. This renewal time is quite long, reflecting the fact that the production rate is small compared with the volume of the ocean occupied by AABW. Yet it is this production rate combined with the relatively low mixing rates which creates the strong density gradients that define the Antarctic Circumpolar Current.

The main formation of AABW is thought to occur in three distinct regions, on the continental shelves of the western Weddell Sea, western Ross Sea and Adélie Land, south of Tasmania. The Adélie Land source of bottom water has always been considered to be negligible (Carmack 1977) compared with the Weddell and Ross Sea sources. However, recent analyses of the volume of the AABW characteristic of these three source regions show that the Weddell, Adélie and Ross sources are respectively 68%, 24% and 8% by volume (Rintoul 1998), that is Adélie Land Bottom Water (ADLBW) is the second largest source. This new result is also supported by a census of Chloro-fluorocarbon (CFC-11) concentrations around the Antarctic continent (Orsi *et al.* 1999), which shows that layer of AABW defined by the CFC-11 is thicker in the Australian–Antarctic basin than in either the Weddell or Ross Seas.

Bottom waters are an important part of the thermo-haline circulation, and increased greenhouse gas scenarios from coupled-ocean-atmosphere models show that the rate of bottom water formation is expected to decrease (Manabe *et al.* 1990, Manabe *et al.* 1991). It is important that these model scenarios are validated with observations. In this paper the geographical distribution of ADLBW in the Australian–Antarctic basin, evidence for its time variability of formation and its links to the Mertz Polynya are described.

BOTTOM WATERS IN THE AUSTRALIAN–ANTARCTIC BASIN

Describing the precise distribution of bottom waters and estimating their production are essential requirements for understanding the mechanisms and sources of bottom water formation. The CFC-11 concentration at 10 m above the ocean floor (fig. 1) is taken from hydrographic data obtained on a voyage of the RSV *Aurora Australis* from January–March 1996 (see Bindoff *et al.* 1997 and Rosenberg *et al.* 1997 for a more complete description of this voyage). These CFC-11 measurements are accurate to ~1% (WOCE standard). Although the source of CFC-11 in the atmosphere is increasing, the rate of increase from 1990 to 1996 is just 6% or about 1% per year (Gras *et al.* 1999). Thus, for the relatively young waters directly above the ocean floor and the shelf waters presented here (<10 years old) there is no need to adjust the CFC-11 values to allow for the time variation in the atmospheric source, and for these data this adjustment is small compared to the effects of mixing. The CFC-11 Chloro-fluorocarbons are transferred from the atmosphere to the oceans through the surface of the ocean. Because CFCs are chemically passive in the ocean, they act as a tracer or dye. The highest concentrations (to first order)

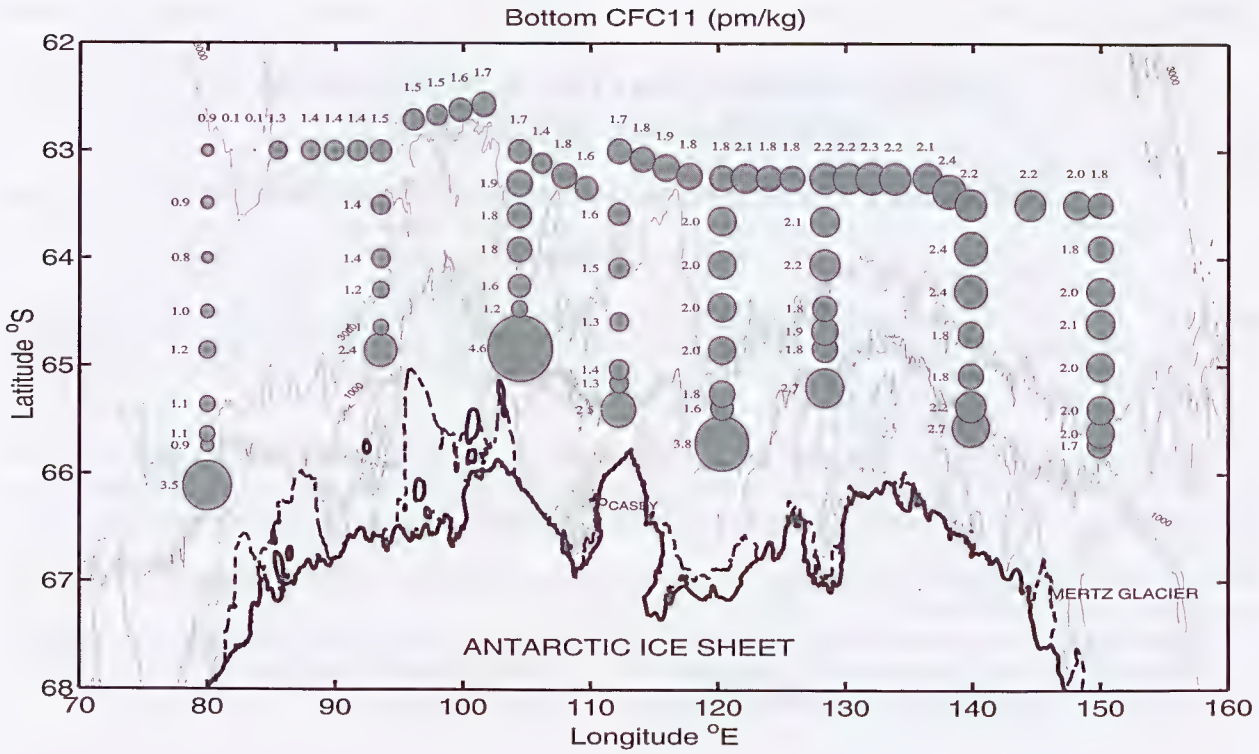

FIG. 1 — The CFC-11 concentration (pmol/kg) taken from the deepest water sample (typically 10 m from bottom) for all CTD stations over the deep ocean. The numbers are the observed CFC-11 concentration at each CTD. The size of the circle gives the amplitude of the CFC-11 concentration. The 1000 and 3000 m depth contours are shown. These data come from the MARGINEX experiment (Bindoff et al. *1997), obtained in January–March 1996. The thick dashed contours show the ice shelves in this region.*

can be interpreted here as waters that have been most recently in contact with the atmosphere. Each of the north–south hydrographic sections (except at 150°E) cross the continental shelf break shown by the 500 m isobath. On the shelf floor, very high CFC-11 concentrations of greater than 4 pmol.kg^{-1} occur, consistent with the moderately rapid overturning of the shelf waters and mixing with the atmosphere. However, these concentrations decrease very rapidly down the continental slope. In the deep ocean, the lowest deep-water CFC-11 concentrations occur in the west (along 80°E) with concentrations less than 1 pmol.kg^{-1}, and these concentrations progressively increase eastward until a local maximum in CFC-11 concentration occurs at 140°E.

At 150°E the CFC-11 concentration decreases again. These lower CFC-11 concentrations are also accompanied by higher salinities and warmer temperatures, consistent with this water originating from the Ross Sea and flowing westwards along the continental rise (Gordon & Tchernia 1972). The increase in CFC-11 at 140°E also accompanies water that is colder, fresher and more oxygen-rich, implying that the bottom waters at 140°E have been mixed with more recently ventilated water originating from the continental shelf somewhere between 140° and 150°E.

Excluding the large values of CFC-11 over the continental shelf/slope break (less than 1000 m), all of the north–south sections show the highest values of CFC-11 (and also the coldest, freshest and highest in oxygen) offshore in waters deeper than 3000 m (fig. 1). Although it appears from these data that the source must be between 140° and 150°E, it is clear that during the summer time there is not a continuous plume of high CFC (cold and fresh and dense) water flowing downslope in either of these two sections. This suggests that the source waters are flowing down the continental slope during the winter or between the two sections or in discrete canyons on the continental slope (Rintoul 1998).

The seasonal variability of bottom water formation is poorly known because the extensive sea-ice cover during winter makes the continental slope and shelf region largely inaccessible to conventional ship-based measurements. However, temperature measurements from 10 m above the ocean bottom from a mooring at 65°S, 140°E in 2600 m of water show a distinctive seasonal signal. The warmest temperatures occur during the February–June period and the strongest cooling in the August–December period (Fukamachi, pers. comm.); this is consistent with the strongest formation being during the late winter–spring.

In addition, the temperature and salinity characteristics of shelf waters during the January–March 1996 voyage of the RV *Aurora Australis* show that the shelf salinities (fig. 2A) are too fresh to form bottom waters, supporting the conclusions from the moored temperature measurements. Although the Ross Sea Bottom Water (RSBW) has distinctive temperature and salinity characteristics present at 150°E, there is no evidence for this signature at 128°E (fig. 2A), where the bottom waters are colder and fresher (labelled as ADLBW). Here, the temperature–salinity correlation for waters < 0°C forms a straight line that is noise free (fig. 2A). The shelf waters have a temperature near the surface freezing temperature (–1.85°C) and a salinity less than 34.5 psu. For this section there is no simple two-end member mixing scheme between the

summer shelf waters with the Modified Circumpolar Deep Water (labelled MCDW) and the ADLBW. By contrast, the CFC-temperature correlation shows a different relationship between the shelf water and ADLBW (fig. 2B). The shelf waters at (–1.85°C), the MCDW and the bottom waters (<0°C) lie along a single straight line. This suggests that in the source region the shelf waters are mixing with MCDW to form bottom water approximately consistent with a two-end member mixing scheme.

Such a two-end member mixing scheme also implies that the shelf salinity during formation of these bottom waters must have been at least as high as 34.63 psu. Typically, the bottom salinity on the continental shelf is 34.4 to 34.5 psu (excluding depressions on the shelf where relict winter water may remain — Gordon & Tchernia 1972, Rintoul 1998). Thus, to form ADLBW a source of salinity is required during winter to increase the bottom salinity on the shelf by at least 0.15 psu.

ON-SHELF TRANSPORT OF MODIFIED CIRCUMPOLAR DEEP WATER

There are two processes for increasing the salinity of shelf waters. The first is through the transport of relatively warm and salty MCDW (fig. 2A) onto the continental shelf (primarily through channels through the shelf break) and the second is through brine rejection from the formation of sea-ice.

Although there are relatively few hydrographic observations on the continental shelf region between 140° and 150°E, there is some evidence from earlier measurements that during summer, MCDW does penetrate onto the continental shelf. MCDW is characterised by a shallow temperature maximum (and salinity maximum). Offshore over the continental slope (north of the 500 m isobath) the temperature maximum is relatively warm (between –0.5° and 0.5°C) and is present along the entire slope between 140° and 150°E (fig. 3). With the exception of the Adélie Depression (142°–145°E), this temperature maximum is always colder than –1.0°C for hydrographic casts south of the 500 m isobath, indicating that very little of the warm MCDW over the continental slope manages to cross the shelf break. However, in the Adélie Depression, the temperature maximum is much warmer (temperatures between –1.0° and 0.5°C) and even higher in the entrance, suggesting a significant onshore flow through the depression in the shelf break at 143°E. Because MCDW is relatively saline compared with the relatively fresh shelf waters (fig. 2), the inflow of this water provides a source of high-salinity water for the formation of bottom water.

ROLE OF POLYNYAS IN BOTTOM WATER FORMATION

Polynyas, which are large persistent openings in sea-ice that form during the winter near the Antarctic Coast, play a central role in the formation of AABW. They are active regions of sea-ice formation, because the cold Antarctic winds (<-30°C and average speeds in excess of 25 m.s^{-1}) freeze the surface waters and then blow this newly formed ice away from the coast. It is this transport of sea-ice from the coast and the shape of the coastline that keep the polynyas open and make these open areas a factor of ten greater in ice production compared with ocean covered in sea-ice (Zwally *et al.* 1985).

The high release of heat to the atmosphere and the high sea-ice production both act to increase the density of the waters below the polynya. In some polynyas, where the bottom topography has an ideal shape, the brine rejection during ice-formation in combination with the on-shelf flow of saline waters from offshore increases the salinity of the water column. When the shelf salinity reaches a critical

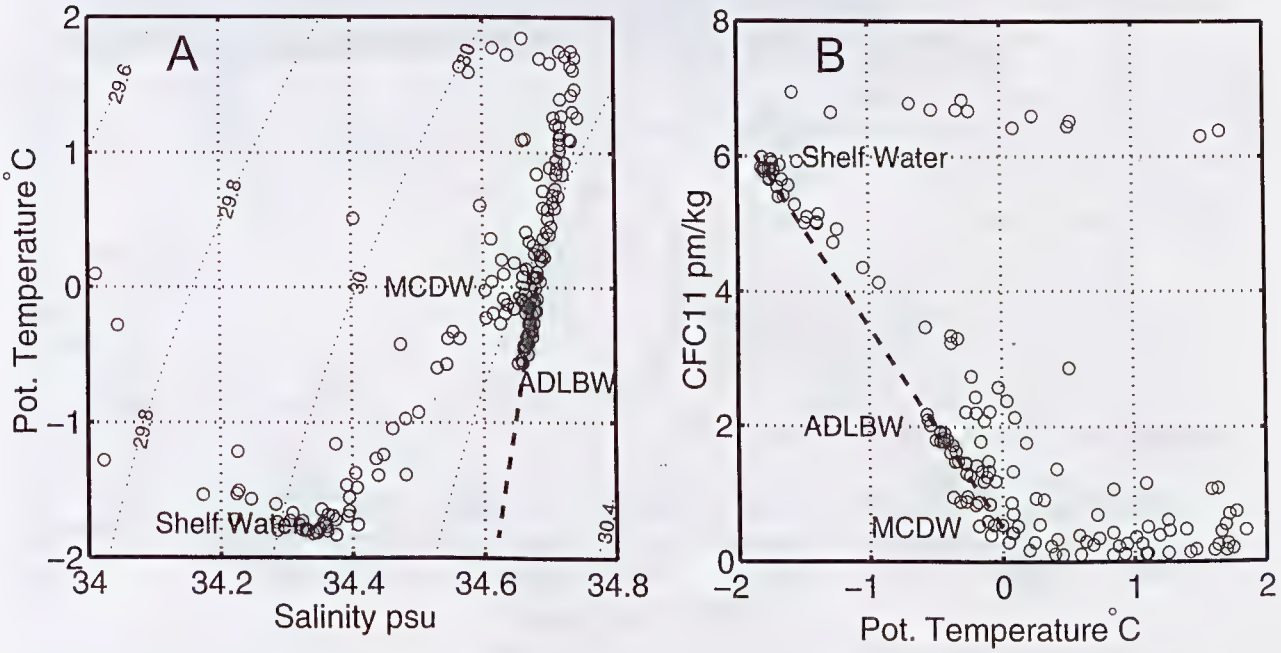

FIG. 2 — Property–property plots of (A) potential temperature and salinity, (B) observed CFC-11 (pmol/kg) and potential temperature. These property–property plots are from the individual water samples from the hydrographic section taken along 128°E in figure 1.

value, these shelf waters become dense enough to flow down the continental shelf to the abyss. The principal reasons for the uncertainties in bottom water formation are that direct observations of the processes are difficult to make from ship and satellite, and that the strongest formation period is believed to be when the sea-ice is at its greatest extent around the Antarctic continent (i.e. September–October).

Brine rejection during sea-ice formation also plays a role in increasing the winter time salinity. A detailed census of the significant polynyas between 40° and 160°E over an eight-year period, using satellite passive microwave data, shows that the largest and most persistent polynyas are the Shackleton Ice Shelf and the Mertz Polynyas with respectively an average area in winter of 30 000 and 23 000 km^2 (Massom *et al.* 1998). However, in spite of its larger size the Shackleton Ice Shelf (near 95°E) is not associated with bottom water formation (fig. 1). The factors that affect production are not the size of the polynya alone, but also include the strength and direction of the local winds, air temperature and water temperature. Along the Antarctic coastline, the Mertz Polynya (67°S, 145°E) is in a region of some of the world's strongest and most persistent winds (Adolphs & Wendler 1995, Ball 1957). It is these factors that give rise to the Mertz Polynya having what is believed to be the greatest ice production in East Antarctica (Cavalieri & Martin 1985).

The Mertz Polynya lies immediately above the Adélie Depression (cf. fig. 4 with fig. 1). This polynya forms to the west of the Mertz Glacier. Its size is also partly controlled by the line of grounded icebergs and fast ice that extends north from this glacier (at 146°E), blocking the westward flow of sea-ice into the sea-ice area. The katabatic winds are strongly offshore at the coastline, turning westwards in 20–30 km. However, the ice-free region extends well beyond the zone of strong winds, and this polynya is wider than most (Massom *et al.* 1998). The unusual width of this polynya is also associated with this region becoming ice-free earlier in the spring than the regions immediately to the east and west (Gloersen *et al.* 1992, Massom *et al.* 1998) and may be the result of the upwelling of warm MCDW in the polynya region. This polynya has a strong seasonal signal (fig. 5) with its areal extent becoming largest typically in October and ranging from 20 000 to 60 000 km^2 for this month. The fastest rate of growth in size of this polynya tends to occur during August–September, which is consistent with maximum sea-ice production and coincides with the colder bottom waters observed in temperature time-series measured offshore (Fuchamachi, pers. com.).

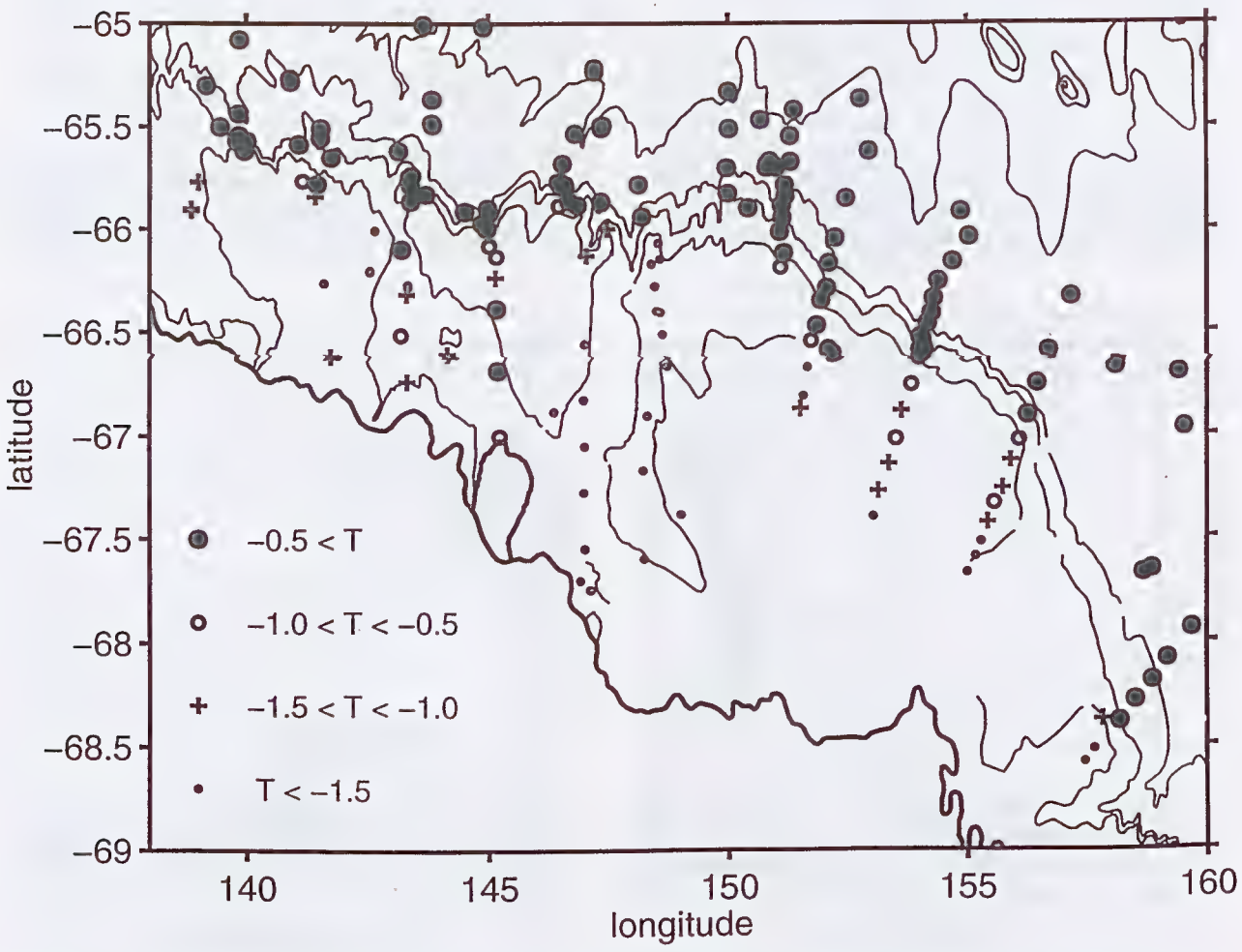

FIG. 3 — The potential temperature of the potential temperature maximum of MCDW plotted using the available historical data. The 500, 1000, 2000 and 3000 m isobaths are shown. Note that the warmest MCDW on the shelf is found in the Adélie depression between 143° and 145°E.

CONCLUSIONS

From these data, the Mertz Polynya appears to play a central role in the formation of ADLBW. It provides additional salinity through high sea-ice production and, because of the cold air temperatures, provides a window for high heat-fluxes from the ocean to the atmosphere. These high heat-fluxes can cool the likely onshore transport of warm (and relatively more saline) MCDW waters, thereby enhancing the overturning circulation within the Adélie Depression caused by the outflow of cold bottom water. In this conceptual model, the Mertz Polynya is being kept open by the winds (i.e. acting as a latent heat polynya) and also by heat transported onshore by MCDW (i.e. acting as a sensible heat polynya). The fact that no MCDW is observed on the continental shelf except in the Adélie Depression also

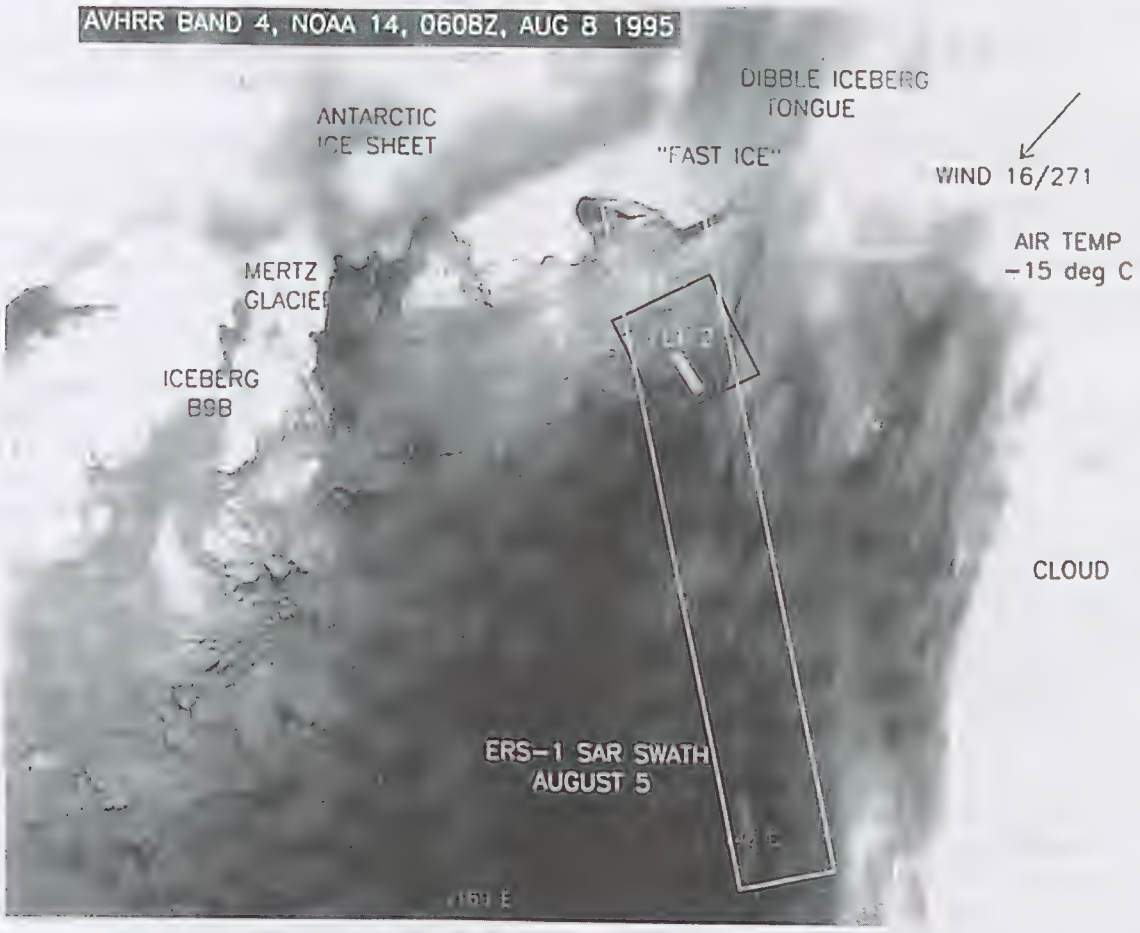

FIG. 4 — An AVHRR channel 4 (thermal infrared) image of the Antarctic coastline taken in August 1995 between 150° and 135°E, south of Tasmania. The Mertz Polynya is the dark region to the west of the Mertz Glacier and adjacent to the Antarctic coastline. The grey-scale gives an indication of the temperature, with the brightest greys corresponding to the coldest reflective surface (glacier ice or clouds) and the darkest regions to open ocean.

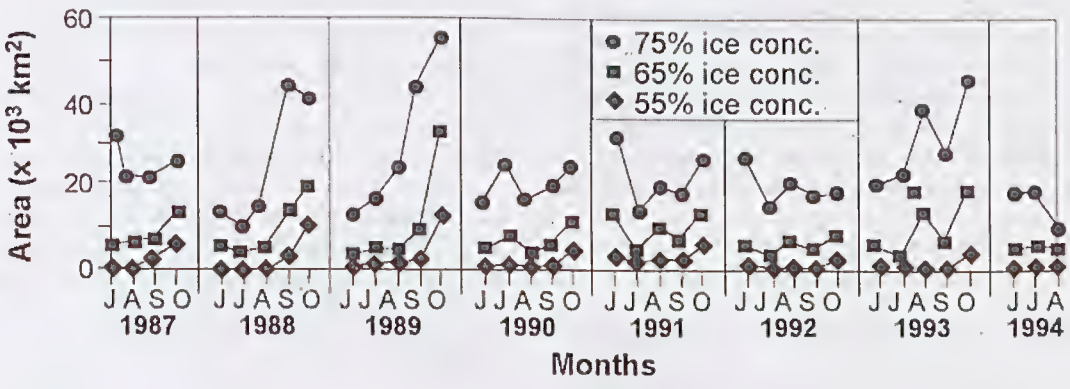

FIG. 5 — Eight-year time series of the area of the Mertz Polynya as determined from the Special Sensor Microwave Image satellite passive microwave observations. The polynya is deemed to be an open area when the sea-ice concentration falls below a specified concentration. In this figure, the open area was determined for three cases where the concentrations are respectively less than 75%, 65% and 55%. From Massom et al. *(1998)*

indicates that the shape of the Adélie Depression and its associated channel through the shelf break is a critical element in the formation of ADLBW.

The essential questions that need to be resolved are the precise role that the onshore transport of MCDW plays compared with the role of ice production within the Mertz Polynya and the rate of production of Adélie Land Bottom Water. These questions are being addressed through a multidisciplinary programme involving sea-ice scientists, meteorologists and oceanographers in July 1999.

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(accepted 5 July 1999)

SEDIMENTOLOGICAL SIGNATURES OF SUB-ICE-SHELF CIRCULATION: AN EXAMPLE FROM VINCENNES BAY, EAST ANTARCTICA

by Peter T. Harris

(with one table and four text-figures)

HARRIS, P.T., 2000 (31:v): Sedimentological signatures of sub-ice-shelf circulation: An example from Vincennes Bay, East Antarctica. *In* Banks, M.R. & Brown, M.J. (Eds): *TASMANIA AND THE SOUTHERN OCEAN. Pap. Proc. R. Soc. Tasm.* 133(3): 57–62. ISSN 0080–4703. Antarctic CRC and Australian Geological Survey Organisation, GPO Box 252-80, Hobart, Tasmania, Australia 7001.

Two cores of Holocene sediment, collected on opposite flanks of the Vanderford Glacier in Vincennes Bay, while representing contemporaneous sedimentation, have different sediment characteristics,with a relatively lower biogenic content on the western side than on the east. These sedimentological signatures are attributed to differences in circulation patterns. Circulation involves landward flow at depth, bringing warmer ocean water into contact with the base of the glacier. This water becomes mixed with fresh meltwater and suspended glacial sediments to form a buoyant plume that rises and flows in a seaward direction under the ice shelf. The landward and seaward flows are deflected to the left in the Southern Hemisphere by the Coriolis effect and, hence, are laterally separated. This pattern explains the differences observed in sediments deposited on opposite sides of the ice shelf in front of the Vanderford Glacier and may be a common feature beneath all large-scale ice shelves.

Key Words: Holocene sediments, ice shelves, circulation, radiocarbon dates.

INTRODUCTION

Water circulation under a floating ice shelf involves landward flow at depth, which brings warmer ocean water into contact with the base of the glacier. This water is mixed with fresh meltwater, which forms a buoyant mixture that rises to the surface while flowing in a seaward direction (fig. 1). Recent modelling work by Williams *et al.* (1998) has shown that the landward and seaward flows are deflected to the left by the Coriolis force and, hence, the flows tend to be laterally separated (fig. 1).

Although there have been several facies models proposed for the deposition of sediments under floating ice shelves (Domack & Harris 1998), only limited reference has been made to the effects of sub-ice-shelf circulation. The sedimentary implications of the lateral separation of sub-ice-shelf flow have not been considered. The near-bed velocity of such flows may be significant with respect to bedload sediment transport. Recently collected sidescan sonar data show large-scale (of the order of 50 m wavelength) bedforms on the middle shelf of Prydz Bay, which may have been produced by sub-ice-shelf flow when the Amery Ice shelf was advanced over the area during the last glacial maximum (O'Brien *et al.* 1999). These dunes are consistently oriented with their steeper lee slope facing landwards, which is consistent with their formation in association with landward-flowing bottom currents such as occur under floating ice shelves (fig. 1).

The aim of the present paper is to examine the sedimentological signatures that might be generated by water and sediment circulation patterns underneath and directly in front of floating ice shelves. Data on sediment properties are assessed in relation to the inferred circulation patterns beneath the floating ice shelf of the Vanderford Glacier in Vincennes Bay, East Antarctica.

METHODS

Gravity cores were collected in 1997 at six locations in Vincennes Bay using the RV *Aurora Australis* (AGSO cruise number 186, Harris *et al.* 1997: fig. 2). The coring device consisted of a 1 tonne bomb connected to 6 m length by 10 cm diameter core barrels (9 cm diameter PVC core liner). Cores 186/5GC7 and 186/6GC8, collected 10 km from the front of the Vanderford Glacier, were used in the present study (fig. 2).

Magnetic susceptibility was measured on whole cores at 2 cm intervals, using a Bartington MS2-C meter connected to a 10 cm diameter coil. Data were corrected for instrument drift and end-of-core effects. Visual descriptions of the split cores were prepared taking note of sediment texture, colour, fossil content, apparent grain size, sorting and sedimentary structures. A preliminary report, giving descriptive information and details of differences in diatom content of the cores, was presented by Harris *et al.* (1997).

Separate subsamples taken at 5–10 cm intervals down-core were analysed for biogenic opal content, using the method outlined by Mortlock & Froelich (1989). Total organic carbon (TOC) content was determined on splits of these samples by the combustion method at the Chemistry Department, University of Tasmania. Eleven AMS C-14 dates were obtained on bulk organic carbon with dilute HCl pre-treatment by the Institute of Geological and Nuclear Sciences, Lower Hutt, New Zealand.

RESULTS

Radiocarbon Dating and Core Chronologies

Details of the radiocarbon ages determined are listed in table 1. The surface ages for the cores are quite large, 9393 years for 5GC7 and 4114 years for 6GC8. These ages are explained from palynology preparations that were made for

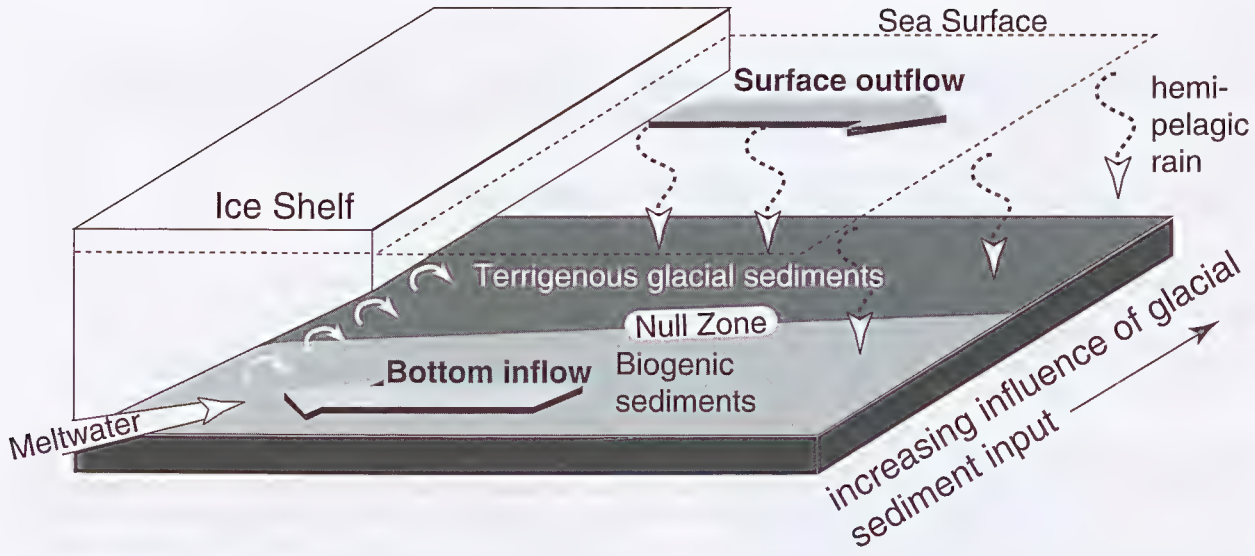

FIG.1 — Schematic diagram showing the circulation pattern of water under a floating ice shelf. Landward flow at depth transports biogenic sediments under the ice shelf and brings warm ocean water into contact with the base of the glacier. This water is mixed with fresh meltwater containing suspended terrigenous sediments, which forms a buoyant plume that rises to the surface while flowing in a seaward direction. Flows are deflected to the left by the Coriolis force, giving rise to a lateral separation of flow. A "null zone" (Domack & Harris 1998) exists in bottom sediment deposits, where the biogenic-marine supply is equal to the glacial-terrigenous supply.

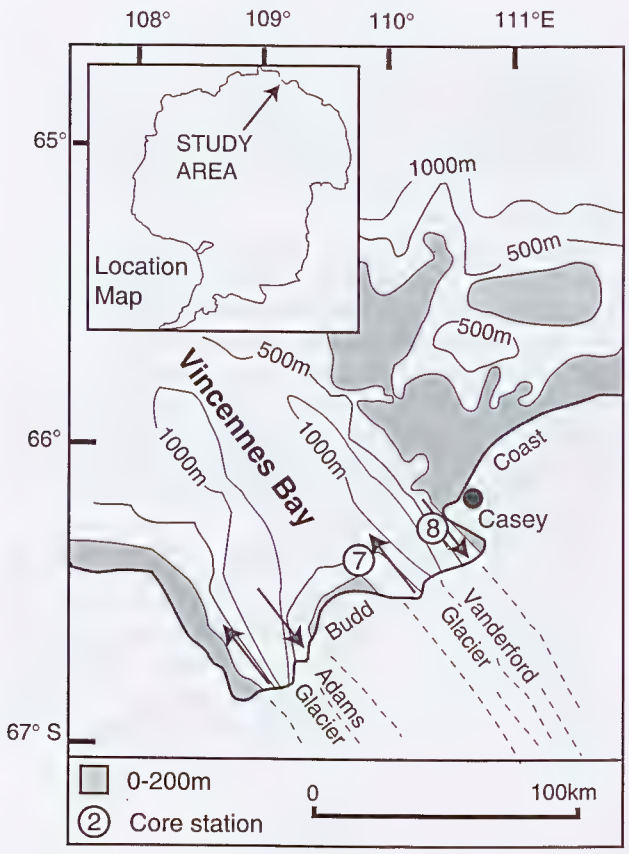

FIG. 2 — Location map showing the positions of cores 5GC7 and 6GC8, located in 1200 m and 1740 m water depth respectively, near the calving front of the Vanderford Glacier.

three samples in each of the cores, which showed the widespread occurrence of Eocene dinoflagellate cysts (A. McMinn, pers. comm.). Hence, the apparent surface ages are related to contamination by recycled ancient organic matter, which dilutes the ^{14}C content of TOC and affects the AMS radiocarbon age (Harris *et al.* 1996; table 1). In order to derive a chronology for the cores, the surface ages (assumed real age 0 years) were subtracted from the ages lower down in each core. This correction appears to be justified because

(1) the recycled Eocene organic matter is apparent throughout the cores in palynology slides;

(2) all of the radiocarbon ages in core 6GC8 and the top three ages in core 5GC7 increase progressively down core, suggesting that the contamination factor is systematic; and

(3) the opal, TOC and magnetic susceptibility time series are comparable between the two cores, using the radiocarbon-derived timescale (see below).

Core Profiles

Core 5GC7 is divided into two separate units based on radiocarbon chronology and lithology. Radiocarbon dates from the upper 200 cm of this core (fig. 3, table 1) depict a consistent increase in age with depth, indicative of sedimentation rates of 23 cm/kyr (0–100 cm) and 10 cm/kyr (100–200 cm). Between 100 and 200 cm the core exhibits abundant bioturbation structures, which are consistent with the slow accumulation rate calculated for this interval. The similarity in the radiocarbon ages below 200 cm suggests that an interval of rapid accumulation occurred, and the possibility exists that the bioturbated unit below 120 cm (fig. 3) includes one or more disconformities. The laminae that are common below 400 cm core depth (fig. 3) exhibit a sharp lower contact with an upper transitional boundary, indicative of turbidites. However, above ~200 cm the core

TABLE 1
AMS ^{14}C ages for bulk organic carbon samples collected in Vincennes Bay, East Antarctica

Core No.	Depth (cm)	Age yr BP	± yrs BP	Corrected age*	Lab Ref. No.†
186/5GC7‡	1	9393	74	0	NZA 8209
	101	13705	78	4312	NZA 8210
	201	23580	160	14187	NZA 8211
	301	21500	120	12107	NZA 8212
	401	21910	120	12517	NZA 8213
	519	20730	120	11337	NZA 8036
186/6GC8§	1	4114	77	0	NZA 8205
	121	7408	68	3294	NZA 8206
	301	9322	62	5208	NZA 8326
	401	10993	74	6879	NZA 8207
	518	12250	80	8136	NZA 8037

* Corrected ages were determined by subtracting the surface age from all ages in each core.
† The laboratory reference numbers are from the New Zealand Institute of Geological and Nuclear Sciences, Rafter Radiocarbon Laboratory, Lower Hutt (NZA).
‡ From 66°30.3'S, 109°57.1'E.
§ From 66°22.0'S, 110°10.4'E.

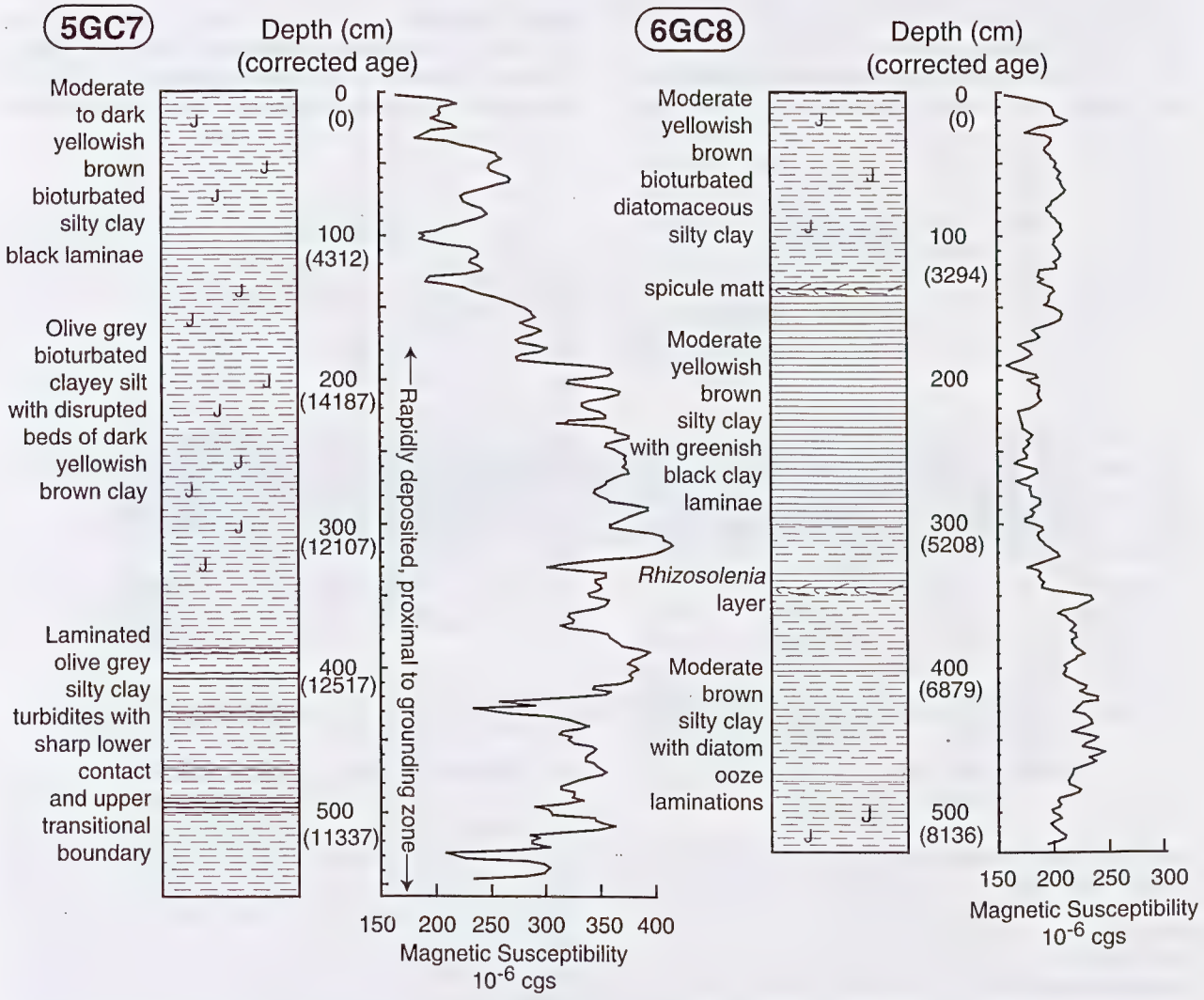

FIG. 3 — Visual core logs and magnetic susceptibility curves for cores 5GC7 and 6GC8 (modified from Harris et al. *1997, to include corrected radiocarbon dates). The presence of bioturbation (mottles and burrows) is shown by "J".*

appears to provide a reasonable radiocarbon chronology (table 1) and the profiles of TOC, opal and magnetic susceptibility over this time interval (0 to ~8 ± 2 kyr BP) are considered here to represent a continuous time series (fig. 4).

Radiocarbon dates from core 6GC8 show a consistent increase down-core (fig. 3, table 1) and suggest a mean sedimentation rate of 64 cm/kyr over the 520 cm length of the core. The upper 130 cm (0–3300 yrs BP) of core 6GC8 is a moderate yellowish-brown, bioturbated, diatomaceous, silty clay (fig. 3). The opal, TOC and magnetic susceptibility time series for this interval (fig. 4) show that the sediment is low in TOC (0.5–0.6%), low in biogenic silica (10–15%) and has a low accumulation rate of about 33 cm/kyr. Below 130 cm the core is moderate yellowish-brown, silty clay with greenish-black laminae containing abundant diatoms (fig 3). This interval is relatively high in TOC (0.5–0.8%) high in biogenic silica (15–30%) and has average sedimentation rates of from 60 to 94 cm/kyr (figs 3, 4).

DISCUSSION

Palaeoenvironmental Interpretation

The shift from high TOC/opal and low magnetic susceptibility at 3.5– 6 kyr BP, to low TOC/opal and high magnetic susceptibility sedimentation after 3.5 kyr BP (fig. 4), is paralleled by a shift from open-water diatoms (*F. kerguelensis*) to sea-ice diatoms (*F. curta*; Harris *et al.* 1997). These changes imply colder conditions and/or more persistent sea ice in the late Holocene. This interpretation is consistent with results of workers from the Antarctic Peninsula (Shevenell *et al.* 1996, Leventer *et al.* 1996), who also inferred greater sea-ice cover for more of the year in the late Holocene. A mid-Holocene warm phase was described by Baroni & Orombelli (1994) as a time of lower winter sea-ice coverage and the time of a "penguin maximum", followed by a period of increased sea-ice coverage in the late Holocene. A mid-Holocene climatic optimum period followed by late Holocene glacial advance has been documented in other onshore climate records from East Antarctica (Ingolfsson *et al.* 1998). Also, the Law Dome $\delta^{18}O$ ice core records suggest that cooler mean annual and winter temperatures have occurred for the last 700 years (Morgan & van Ommen 1997) and a contemporaneous decrease in winter snow accumulation at the Law Dome ice margin has been proposed (Goodwin 1996). The shift from biogenic to siliciclastic dominated sedimentation may be associated with an advance of the Vanderford and Adams Glacier system, consistent with the evidence for an advance of the Law Dome ice-sheet margin since 4000 yr BP (Goodwin 1996).

Influence of Circulation Patterns on Sedimentation

The records of changing sedimentation patterns observed in the cores are also related to water circulation and sediment transport patterns within Vincennes Bay. Core 6GC8 is located close to a broad, shallow shelf (fig. 2) which provides

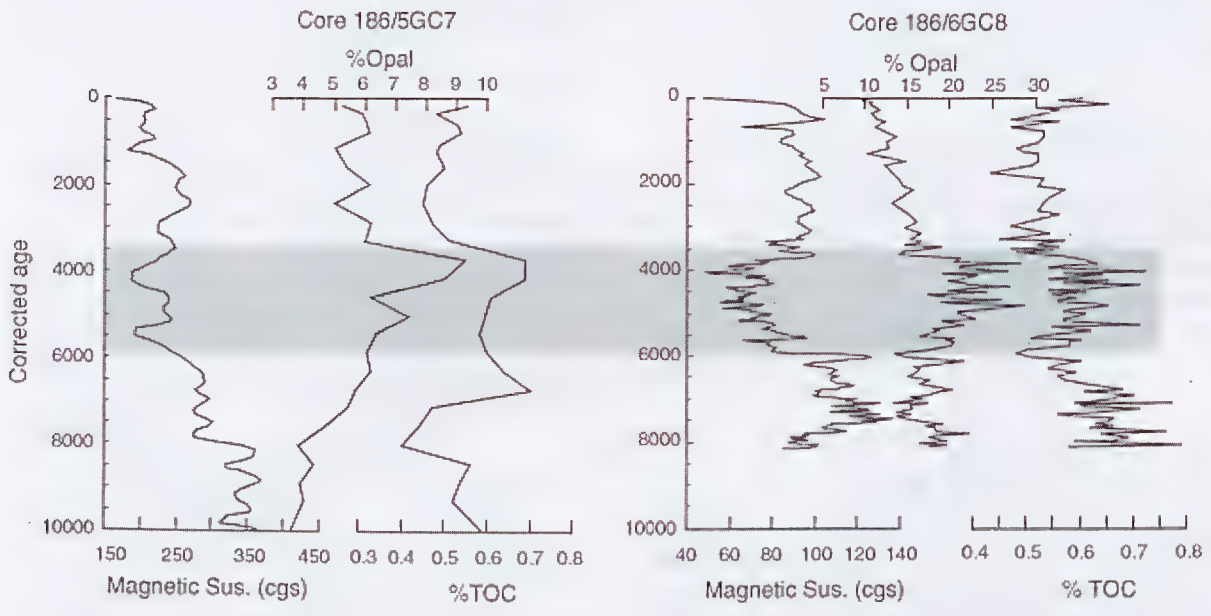

FIG. 4 — Down-core profiles for cores 5GC7 and 6GC8, showing magnetic susceptibility, percentage opal and percentage TOC versus time. The shaded area illustrates that both cores contain a similar record showing a mid-Holocene (3.5–6 kyr BP) low in magnetic susceptibility (glacial terrigenous sediment) and high in TOC and opal content. Core 5GC7 exhibits high absolute values of magnetic susceptibility, with a mean of 308 ± 60 x 10^{-6} cgs and a maximum of 416 x 10^{-6} cgs at a depth of 310 cm. Opal content is relatively low, with a mean value of 5.3 ± 1.4%, a maximum of 9.3% and a minimum of 3.5%. TOC content is also low, with a mean value of 0.61 ± 0.11%, a maximum of 0.95% and a minimum of 0.40%. Core 6GC8 exhibits lower absolute values of magnetic susceptibility, with a mean of 90.6 ± 18.5 x 10^{-6} cgs and a maximum of 136 x 10^{-6} cgs at a depth of 455 cm. Opal content is relatively high, with a mean value of 17.6 ± 4.1%, a maximum of 28.7% and a minimum of 9.7%. TOC content is similar to 5GC7, with a mean value of 0.58 ± 0.07%, a maximum of 0.79% and a minimum of 0.43%.

a source of reworked biogenic and terrigenous sediments swept into the adjacent glacial trough by southeastwards flowing currents (Harris *et al.* 1997). This would explain the relatively higher sedimentation rate at core 6GC8 (mean of 64 cm/kyr) than that at 5GC7 (10–23 cm/kyr).

Another important factor is the sub-ice-shelf circulation and lateral flow separation pattern that might be expected under the floating ice shelf of the Vanderford Glacier (fig. 1). Such a circulation pattern would account for the relatively higher biogenic silica and TOC values found throughout core 6GC8 in comparison with core 5GC7. Whereas both core sites would experience hemipelagic sediment rain (fig. 1), core 6GC8 would be expected to have higher biogenic input, due to the landward current flow delivering mainly marine-derived biogenic sediments. In contrast, core 5GC7 would be expected to have higher terrigenous sediment input, due to the seaward flow delivering mainly glacially derived sediments (fig. 1). If the recycled Eocene dinoflagellate cysts are derived from this glacial terrigenous source, it would account for greater TOC contamination and, hence, explain the greater apparent surface radiocarbon age in core 5GC7 compared with core 6GC8 (table 1). However, the meltwater may itself provide a source of ^{14}C-dead organic matter and dissolved carbon.

One core studied by Domack *et al.* (1989) collected off Adélie Land had a surface radiocarbon age of about 5500 years, which these workers attributed to old carbon released in glacial meltwater. The actual source of the ^{14}C depleted material is unclear. It probably cannot be attributed to CO_2 gas in air bubbles trapped in the ice, as this concentration is far too low. It may be that dissolution of ancient calcareous rocks under the grounded ice sheet provides a source of the ^{14}C depleted meltwater. Such a mechanism was proposed by Heier-Nielsen *et al.* (1995) to explain relatively large ^{14}C surface sediment ages in some samples from Danish fiords. Goodwin (1988) studied basal meltwater near Casey Station (fig. 2) and found that it had a high solute load, with concentrations of HCO_3 of 0.00352 mol l^{-1}, which is about 1.5 times that of normal seawater. The prediction of the sub-ice-shelf flow model is that one should encounter greater meltwater flow near the surface along the left flank of floating ice shelves, facing seawards (fig. 1). Consequently, one would expect to observe a corresponding increase in ^{14}C dilution in the surface waters on the left (western) flank of the Vanderford Glacier, which is consistent with the ^{14}C age of the surface sediment being greater for core 5GC7 (9393 yrs) than core 6GC8 (4114 yrs — table 1).

Refinement of Sub-ice-shelf Facies Models

In their review of sub-ice-shelf sedimentary facies, Domack & Harris (1998) described a succession of facies in a seaward direction, from sub-ice-shelf beneath a basal debris zone, sub-ice-shelf distal to a debris zone, calving-line transition and, finally, to the open marine facies. At some distance seawards of the grounding line, beneath wide (> 10 km) floating ice shelves, theoretically there exists a "null zone" in sedimentation, where the volume of fine-grained, glacial-terrigenous sediment deposited is equal to the fine-grained hemipelagic component advected landwards under the ice shelf by recirculating currents. This landward advected marine sediment includes diatoms and other phytoplankton together with fine-grained, iceberg-rafted debris released in the open marine setting (Domack & Harris 1998).

Based on the lateral separation model (fig. 1), it is evident that this "null zone" does not exist in only two dimensions. Rather, it should trend obliquely across the ice shelf or even subparallel to the axis of ice flow (fig. 1). Its orientation may also vary temporally, as a function of meltwater discharge and/or other oceanographic factors associated with the density-driven, sub-ice-shelf circulation. Hence, the sub-ice-shelf facies succession, and particularly the "null zone" described above, will exhibit spatial and temporal variability.

CONCLUSIONS

A new oceanographic model for circulation under floating ice shelves provides the basis for refinement of existing sub-ice-shelf sedimentation models. Ice shelves that are large enough in scale for the Coriolis force to cause lateral separation of flow are expected to have near-bottom inflow on the right side and surface outflow on the left side (facing seawards in the Southern Hemisphere). This flow pattern results in sediments deposited on the right flank of ice shelves being higher in biogenic silica and lower in terrigenous sediment in comparison with sediments deposited on the left flank. In this model, the "null zone" of glacial versus marine-sourced sedimentation should trend obliquely across the seafloor beneath an ice shelf or possibly subparallel to the axis of ice flow. Sediments deposited in front of the Vanderford Glacier during the Holocene exhibit higher biogenic silica and lower terrigenous sediment content on the right (eastern) flank compared with sediments deposited on the left (western) flank. This sedimentation pattern is attributed here to the lateral flow separation model of sub-ice-shelf circulation, and such a pattern is expected to occur beneath all ice shelves subject to similar circulation and sediment transport processes.

ACKNOWLEDGEMENTS

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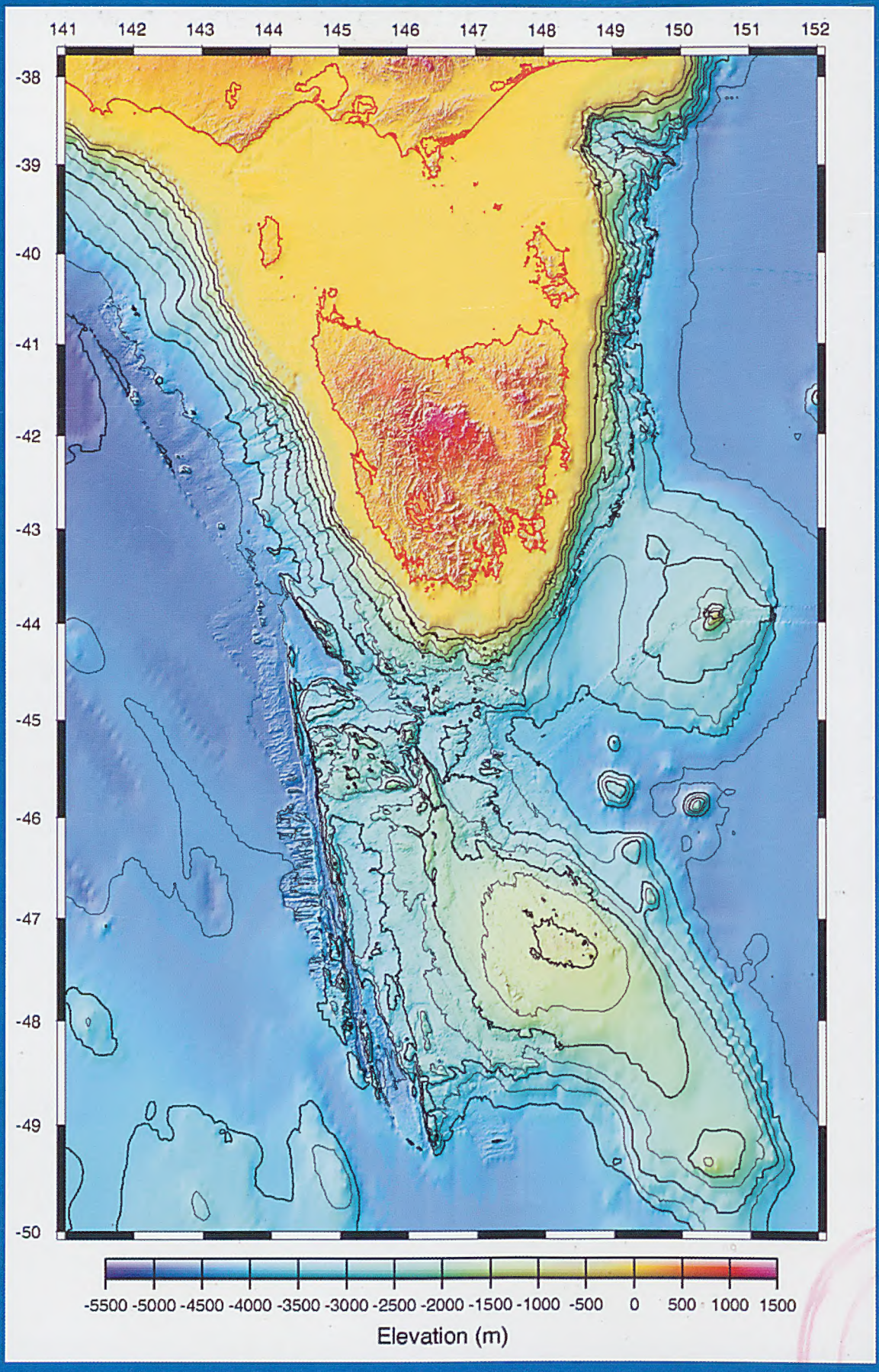
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Elevation (m)